SAN FRANCISQUITO CREEK HYDROLOGY STUDY

Hydraulics, Hydrology and Geomorphology Unit

FINAL (ADDENDUM #1)

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DECEMBER 2016

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ADDENDUM #1

An error was discovered after Corps ATR certification where the incorrect k-value was used to interpolate the 50-yr peak flows in the original report dated November 2015. The k-value was replaced in this addendum, which is dated December 2016. The only changes to the report are in the 50-yr column in Table 15. The changes are documented below.

Table 15: Design Flows (Addendum Updates)

Location	50-Yr Original (2015)	50-Yr Addendum (2016)
Searsville Inflow	3,880	3,700
Searsville Outflow	2,760	2,630
Bear Creek U/S SFC	2,670	2,570
Los Trancos U/S SFC	1,410	1,350
SFC U/S Los Trancos	5,750	5,500
USGS	7,010	6,710
Pope Chaucer	7,490	7,170
US-101	7,730	7,400
K-Value	1.77716	1.72033

The U.S. Army Corps of Engineers San Francisco District Water Resources Section was notified of the change, reviewed the update, and approved the addendum because there was a minimal adjustment to the 50-yr event flows that was determined insignificant.

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APPENDICES

Appendix A: Technical Memorandum - Effect of Searsville Lake on Large Storm Events. SCVWD. March 25, 2015.

Appendix B: US Army Corps of Engineers Agency Technical Review (ATR) Certification background documents.

Attached separately as electronic files

- HEC-RAS v5.0 BETA Searsville 2D Hydraulic Model
- HEC-HMS v4.0 San Francisquito Hydrologic Model
- SFC Flood Frequency Analysis PeakFQSA Output
- Balance Hydrologics Recorded Data Spreadsheet
- Hydrologic Parameters Spreadsheet
- Channel Routing Spreadsheet
- Design Rainfall Spreadsheet
- 2D Model Output Spreadsheet
- Model Plans Spreadsheet

1. INTRODUCTION

1.1. BACKGROUND

San Francisquito Creek forms the boundary of the Santa Clara Valley Water District's (SCVWD) jurisdiction to the north with San Mateo County. The watershed is approximately 45 square miles, with the majority of the watershed in the rural foothills of the San Francisco Peninsula. The Creek's watershed impacts the cities of Palo Alto, East Palo Alto, and Menlo Park. Stanford University is also a major landowner in the region and owns several reservoirs within the watershed.

San Francisquito has three main tributaries that combine to form the creek proper once it leaves the foothills and enters the urbanized valley. Bear Creek is the northernmost tributary and is unimpaired. To the south, Searsville Lake and Dam collect runoff from Alambique, Dennis Martin, Sausal, and Corte Madera Creeks. Searsville Lake offers some attenuation, but has experienced severe sedimentation over time. On the southeastern edge of the watershed, Los Trancos Creek flows unimpaired, passing Felt Lake, a diversion pond owned by Stanford. All three of these tributaries meet before traveling downstream toward the bay through urbanized neighborhoods.

A location map with information about the creek watershed and sub-watersheds is on Figure 1.

1.2. PURPOSE

The purpose of this report is to update the 2007 San Francisquito Hydrology Report[1] by improving the following items from the old report:

1. Upgrading the numerical model from HEC-1 to HEC-HMS v4.0.
2. Characterizing the routing effects of Searsville Lake and dam by using a 2D hydraulic model.
3. Using revised and improved methodology for design storms, loss, and Clark's hydrograph parameters (Tc & R).
4. Calibrating the numerical model to historical storms.
5. Performing a flood frequency analysis (FFA) on the USGS stream gage and validating the hydrologic design model to the FFA.

To do this, a new hydrologic model that reflects the existing San Francisquito Creek watershed was developed. This model will be used to determine revised 1% and 10% design flows for the entire creek.

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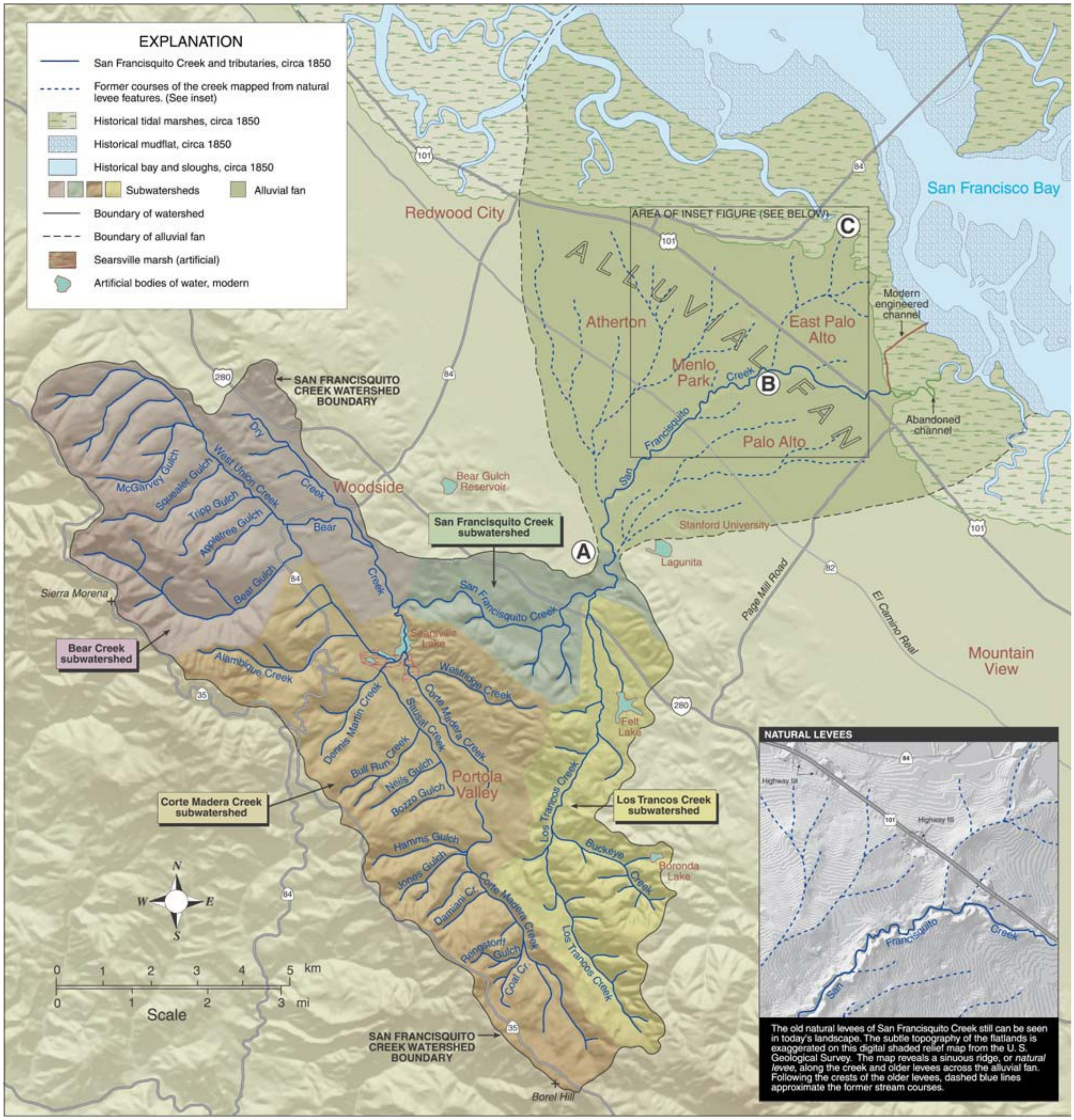
[1] Wang, James et al. SCVWD. San Francisquito Creek Hydrology Report. April 2006, Revised December 2007.



The old natural levees of San Francisquito Creek still can be seen in today's landscape. The subtle topography of the flatlands is exaggerated on this digital shaded relief map from the U. S. Geological Survey. The map reveals a sinuous ridge, or *natural levee*, along the creek and older levees across the alluvial fan. Following the crests of the older levees, dashed blue lines approximate the former stream courses.

Figure 1: San Francisquito Creek Watershed Map

2. MODEL INPUT PARAMETERS

2.1. WATERSHED DELINEATION

Sub-basin watershed delineation was performed by using the ArcHydro add-on to the original ArcGIS software suite. A digital elevation model (DEM) was created from two sources. For Santa Clara County, the 2006 LiDAR data was used, while for San Mateo County, USGS data was used. These elevation datasets were used to determine flow accumulation patterns and ultimately sub-basin delineations. Each sub-basin within an urban area was double checked manually to ensure that terrain features not picked up by the DEM were included, such as walls and levees. In addition, delineations were manually created at stream gage locations and dams.

Two delineated sub-basins were determined not to contribute to San Francisquito Creek flow. The first is the area tributary to Felt Lake. The second is the Stanford golf course.

2.2. SURFACE RUNOFF METHOD

The Army Corp's HEC-HMS hydrologic modeling software was used to perform this study. The Soil Conservation Service (SCS) Curve Number (CN) method was selected as the loss method, and Clark's Unit Hydrograph (CUH) was selected as the transform method. Since the model will primarily be used to determine design flow rates, it will be used as an event-based model, which is appropriate for the SCS loss method. The CUH method is robust for watersheds of different sizes and shapes. Based on previous experiences, the SCS method combined with CUH transform method works well within the Santa Clara Valley Watershed. This method has been used on studies in adjacent Matadero and Steven's Creek watersheds [2], as well as studies in the nearby Saratoga and San Tomas Creek watersheds [3], all of which have drainage areas from 20 to 45 square miles.

2.3. SUB-BASIN PARAMETERS

Six different variables; (2.3.1) Area, (2.3.2) Initial Abstraction, (2.3.3) Curve Number (CN), (2.3.4) Impervious Area, (2.3.5) Time of Concentration, and (2.3.6) Reach Coefficients must be characterized for each sub-basin and are listed below in further detail.

2.3.1. AREA

This is defined as the total area of the sub-basin in square miles. It is determined from area measurements performed in ArcGIS.

2.3.2. INITIAL ABSTRACTION

Initial abstraction represents the initial loss on each sub-basin, and also has bearing on the runoff equation used in HEC-HMS for CN method. The default relationship outlined in the SCS CN loss method is that initial abstraction is 20% of sub-basin storage. However, recent research[4],[5] suggests that 5% is a more appropriate value. Storm calibrations within this model have also supported the 5% value suggested by Hawkins and Lim et al. The initial abstraction used for rural sub-basins is defined by:

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[2] SCVWD. Lower Peninsula Watershed Hydrology Report. July 2004, revised December 2007.

[3] SCVWD. Hydrology Report – Saratoga and San Tomas Aquino Creeks. May 8, 2013.

$$\text{Initial Abstraction} = 0.05 \times \left(\frac{1000}{CN} - 10\right)$$

While changing the initial abstraction for the SCS CN method, proper procedure dictates that the CN be modified as well, since HEC-HMS adjusts rainfall excess based on initial abstraction, and initial abstraction is related to the sub-basin storage index (S) that was fixed using a 20% ratio during the development of the SCS method. Since S is directly related to CN, the CN number would need to be adjusted as well if the ratio was changed to 5%. However, calibrations suggested that overall volume was matching observations without adjusting CN.

2.3.3. CURVE NUMBER (CN)

Curve number represents the pervious sub-basin characteristic for surface runoff. Internal parameters of curve number are; soil group, land cover type, and antecedent moisture condition (AMC). Curve number development was performed in accordance with a District memorandum [6] on SCS CN determination.

2.3.4. IMPERVIOUS AREA

Impervious area characterizes the amount of area, in percent, within the sub-basin that will experience negligible loss. These areas are generally considered paved urban areas. This value is based on the 2006 National Land Cover Dataset (NLCD) and is aggregated for each sub-basin in ArcGIS.

For watersheds with large amounts of urban areas, an impervious area reduction is commonly used to account for unconnected impervious areas. However, due to the majority rural makeup of the San Francisquito watershed, a reduction was not used.

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[4] Kyoung Jae Lim, et al. Effects of Initial Abstraction and Urbanization on Estimated Runoff Using CN Technology. June 2006. Journal of the American Water Resources Association.

[5] Hawkins, Richard H. Woodward, Donald E. Runoff Curve Number Method: Examination of the Initial Abstraction ratio. 2002.

[6] Xu, Jack. SCVWD Technical Memorandum. SCS Curve Number Determination, Update #1. January 10th, 2015.

2.3.5. TIME OF CONCENTRATION (Tc)

Time of concentration is the maximum travel time for each sub-basin. The velocity method described in NEH Chapter 15[7] was used to determine time of concentration. General guidelines used by the District are outlined in a technical memorandum [8] on this subject.

In general, possible collectors and collector combinations were categorized into similar slopes and cross sections. A reiterative process was used to solve manning's equation for velocity, given a certain flow depth. The flow depth was determined from a given flow rate that was selected based on USGS regression equations. The equations serve as a broad estimation of the flow for different recurrence events given the sub-basins characteristics. Therefore, several times of concentrations for each sub-basin were developed, depending on the flow.

2.3.6. STORAGE COEFFCIENT (R)

The storage coefficient represents the amount of storage and attenuation that will not be lost within the sub-basin for the CUH method. This variable will change the shape of the runoff hydrograph. Studies [9] have shown that the storage coefficient ratio remains constant over a large watershed area:

$$RRIIIIIIAA = \frac{RR}{RR + TTAA}$$

A ratio above 0.5 implies more storage and a wider hydrograph with a smaller peak flow. A ratio below 0.5 implies a narrow response with a larger peak flow. This value is held constant for each general topographic area within the Coyote Watershed for all calibration events. For the entire San Francisquito Creek watershed, calibrations supported a storage coefficient ratio of 0.5.

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[7] USDA NRCS. Part 630 Hydrology, National Engineering Handbook. Chapter 15, Time of Concentration.

[8] Xu, Jack. SCVWD Technical Memorandum. Time of Concentration (Tc). November 10, 2014.

[9] USACOE HEC-HMS Users Manual v3.5. August 2010. Chapter 7, pg.141.

2.4. REACH ROUTING PARAMETERS

All reach routing was performed from sub-basin to sub-basin using the Muskingum-Cunge method in the hydrologic model, except for Searsville Reservoir. Muskingum-Cunge is an extension of the Muskingum method, which overcomes difficulty in estimating parameters that are not physically based. According to the HEC-HMS technical reference manual[10], Table 19 lists the Muskingum-Cunge routing method as having the most flexibility. In addition, this routing method has been used successfully in previous studies, similar to CUH as mentioned in Section 2.2.

Slopes were taken using elevations at 10% and 85% of the reach length. Manning's roughness coefficients and channel geometry were estimated using aerial images and field visits. For creek reaches downstream of the Los Trancos Creek confluence, a HEC-RAS existing conditions model is available[11]. Channel geometries and slopes were taken from this model and input into the hydrologic model. These geometric parameters did not change during calibration and are summarized in Table 1.

The following assumptions were made to fit the scope of this report in determining design flows:

- All stream channels contain all the flows. There are no breakouts or spills.
- There are no flows entering or leaving the watershed boundaries from spills.

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[10] USACOE HEC-HMS Technical Reference Manual. March 2000.

[11] Noble Consultants. Final Report – San Francisquito Creek Hydraulic Modeling and Floodplain Mapping, Existing Condition. Volume I: Channel Hydraulic Modeling. August 2, 2010. Prepared for USACE SF District.

Table 1: Reach Routing Parameters

Reach ID	Length (ft)	Channel n-value	Slope (ft/ft)	Slope/n Determination
SFQ_A1_ChnRT	9596	0.05	0.002111	GIS & Field Visit
SFQ_AA14_Z_ChnRT	5293	0.05	0.003862	GIS & Field Visit
SFQ_E_z_ChnRT	18751	0.043	0.00544	RAS
SFQ_G1_ChnRT	7200	0.05	0.021	GIS & Field Visit
SFQ_G2_Z_ChnRT	11000	0.05	0.0137	GIS & Field Visit
SFQ_G5_Z_ChnRT	2049	0.05	0.007112	GIS & Field Visit
SFQ_G6_Z_ChnRT	6264	0.043	0.00694	RAS
SFQ_H_Z_ChnRT	7062	0.043	0.00565	RAS
SFQ_J2_Z_ChnRT	4971	0.043	0.00322	RAS
SFQ_L_Z_ChnRT	10142	0.043	0.00252	RAS
SFQ_M_Z_ChnRT	9361	0.043	0.00201	RAS
SFQ_N_Z_ChnRT	7761	0.03	0.00045	RAS
SFQ_B1_ChnRT	17495	0.05	0.005323	GIS & Field Visit
SFQ_D_ChnRT	6588	0.06	0.002921	GIS & Field Visit
Reaches only in "No Searsville Lake" Model				
SFQ_BB11_ChnRT	7172	0.05	0.003923	GIS & Field Visit
SFQ_BB13_ChnRT	6616	0.05	0.006561	GIS & Field Visit
SFQ_C6_ChnRT	6197	0.05	0.003009	GIS & Field Visit

2.5. DETENTION FACILITIES

In the San Francisquito Creek watershed, there are three notable detention facilities; Felt Lake, Lake Lagunita, and Searsville Lake.

Felt Lake is used as a water supply source for Stanford University, and generally does not impact the overall flow of the watershed. This is also true for Lake Lagunita, which detains runoff from the campus golf course. Conversations with Stanford facilities revealed that Felt Lake and Lake Lagunita have never overtopped, even during the storm of record in 1998. In addition, a sensitivity study performed by peer review showed very little impact. Therefore, both lakes and the contributing runoff area were taken out of the model.

Searsville Dam is a 68-foot-high concrete gravity dam that is comprised of large concrete blocks. It was built in 1892 by the for-profit Spring Valley Water Company, and was acquired by Stanford University in 1919. Stanford University has not used the reservoir for water supply since 2013[12]. Searsville Lake impounds almost 15 square miles of the watershed behind it.

Due to ongoing sedimentation, at rates that are estimated to vary between 3.6 acre-feet to 23.5 acre-feet per year over the lifespan of the dam [13], the lake only has about four feet of storage before spilling, if empty. This amounts to less than 10% of the original water capacity, which is approximately 90 acre-feet. However, the backwater effect caused by the dam, the wetland behind it, and surrounding low-lying areas, has caused significant attenuation in the past. Observations from historical events suggest that typical volume/discharge methods would not be sufficient. To route the flow from the upland tributaries, through the lake, and out the dam, a 2D hydraulic model was used.

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[12] Stanford University Website. http://news.stanford.edu/searsville/. Updated 5/5/2015. Accessed 10/5/2015.

[13] Northwest Hydraulic Consultants, Balance Hydrologics, HT Harvey Associates, Jones & Stokes, Matt Kondolf, Jerry Smith. Searsville Lake Sediment Impact Study. March 2002. Stanford University, Facilities Operations

2.6. SEARSVILLE LAKE 2-D HYDRAULIC MODEL

HEC-RAS Version 5.0 BETA, October 2014 release, was used to properly model Searsville Lake. A 2D computation mesh was created by using a *.LAS dataset from the 2006 LiDAR survey that generated a digital terrain model with 10’ x 10’ squares. This dataset was cleaned to remove errant reflectivity data from foliage and buildings by the survey vendor. Relevant hydraulic structures were inputted with data from Balance Hydrology’s 1D HEC-RAS model[14] of Searsville that was sent to the District for review in 2014. The outfall of the entire model was modeled as a 2D Boundary Condition Line, whose conditions were determined using a rating curve generated from Balance Hydrology’s model. This curve was double checked with recorded stage and flow data from historical events, which was also provided by Balance.

The 2D Boundary Condition Line spans six grid elements, and during simulation, five of those grid elements are wetted. Due to program limitations in the beta, water surface elevations can only be determined on a grid-by-grid basis while in the 2D domain. Conversation with Gary Brunner, lead developer at HEC, revealed that the computational scheme allows for different water surface elevations within each grid at the boundary condition line. Each grid independently uses the rating curve based on its connection at the boundary condition line. Therefore, there are slight variations in the water surface elevations, depending on grid characteristics. To force a singular output for the water surface, the 2D domain would need to be connected to a 1D cross section within the reservoir. Since bathymetry is not available, the five wetted grids will be averaged to determine a single water surface elevation, which will be used to determine flow from the rating curve.

Late in the peer review process, inaccuracies in the terrain data were discovered regarding the resolution of Corte Madera Creek and the Stanford Causeway gap. The former was addressed by using recently surveyed cross sections present in an existing Balance Hydrologics HEC-RAS model. The cross sections were used to adjust the terrain to reflect surveyed conditions. For the Stanford Causeway, the bridge piers in the crossing were added to the terrain. The bridge deck was not modeled since the 100-yr WSEL does not reach the low chord. A sensitivity analysis was performed between the two sets of terrain using both the 24-hr and 72-hr 100-yr design storms. The outcome was a 0.05’ difference in WSEL at the dam and a resulting flow change of under 5%. Therefore revised terrain was only used in determining the 10-yr and 100-yr design storms, while the original terrain was still used for calibration and sensitivity studies.

Computational point spacing for the mesh was set at 100’ x 100’ and 50’ x 50’, depending on the detail required. A sensitivity analysis that ran the same model at a 10’ x 10’ mesh showed negligible output difference. The diffusive wave computational method was selected over the full dynamic solution due to the lack of potential energy losses through obstructions. A sensitivity analysis using different methods also yielded negligible difference.

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[14] Sears_US_JPA_052114.prj. Balance Hydrologyis Stanford University’s consultant.

To properly characterize the lake, several historical calibrations needed to be run to determine if the model is accurate. When available, stream gage data was used as input into the model. HEC-RAS inputs from other tributaries that were not gaged were estimated. Using the following storm events, a final manning's roughness coefficient of 0.1 worked well for all the storms.

- December 2012 (Figure 2)
- March 2011 (Figure 3)
- January 2010 (Figure 4)
- December 2005 (Figure 5)
- February 1998 (Figure 6)

To estimate the HEC-RAS inflow inputs from the Searsville Lake tributaries, several methods were employed. For the 2011 and 2010 events, only one tributary (Corte Madera Creek) was gaged. For 1998, there were no gages upstream of the dam. These events also had reliable gage adjusted radar rainfall data, and were used in the historical calibrations for the hydrologic model. Therefore, outputs from the HEC-HMS hydrology model were used as tributary inflow inputs for the HEC-RAS models. Parameters used in the HMS model were the same as in the model calibrations for the specific event.

For the 2005 event, only Corte Madera Gage was gaged. However, rainfall data was not reliable. Therefore, the remainders of the tributary inflows were determined by scaling the Corte Madera Creek hydrograph based on drainage area.

The 2012 event had two gaged tributaries. Additionally, a third tributary had visual observations for estimated flow. For the remaining tributaries, flow was determined by scaling the hydrographs from the average of the two gaged tributaries, much like in the 2005 event. However, for the tributary with visual observations, the hydrograph was modified so that the observed flow values properly fit within the rising and receding values of the hydrograph.

Using the calibrated 2D hydraulic model and recorded data, a separate technical memorandum [15] was published. This report attempted to quantify the causes of attenuation for Searsville Lake and the effects of the Lake on San Francisquito Creek during significant storm events. This memorandum is included in this report in Appendix A.

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[15] Xu, Jack. SCVWD. Technical Memorandum - Effect of Searsville Lake on Large Storm Events. March 25, 2015.

Figure 2: Searsville Lake Detail Map

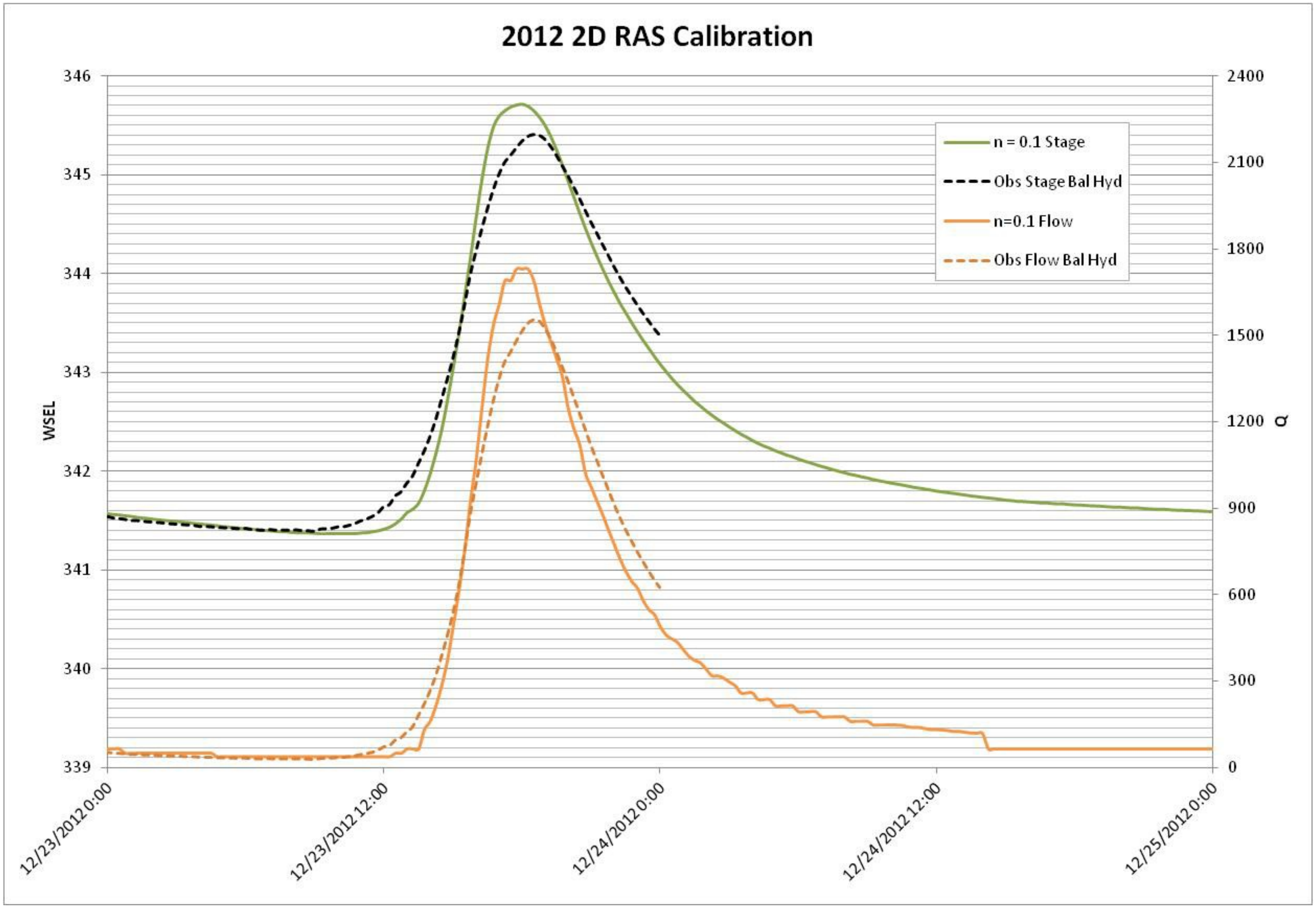


Figure 3: 2012 Searsville 2D Model Calibration

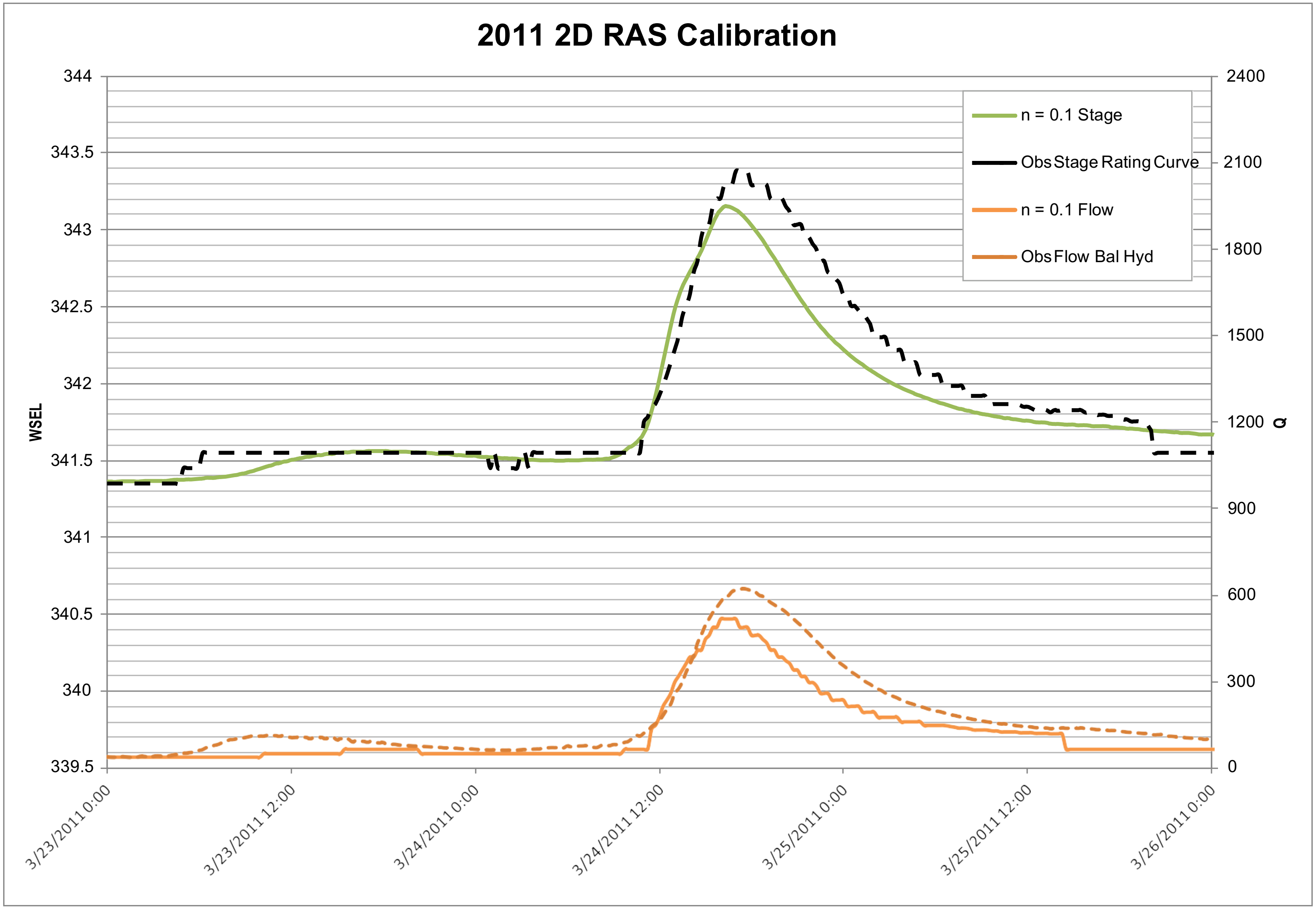


Figure 4: 2011 Searsville 2D Model Calibration

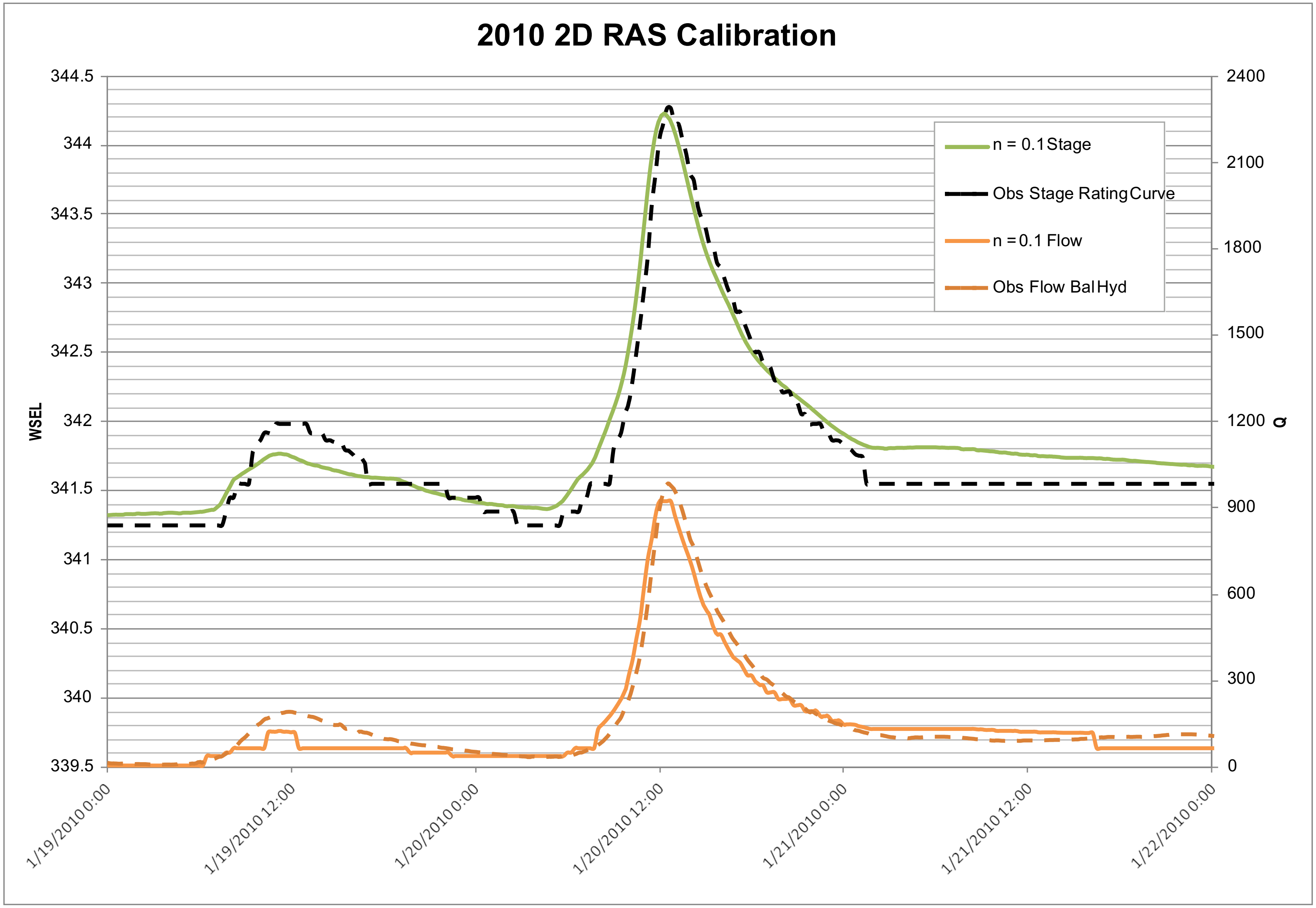


Figure 5: 2010 Searsville 2D Model Calibration

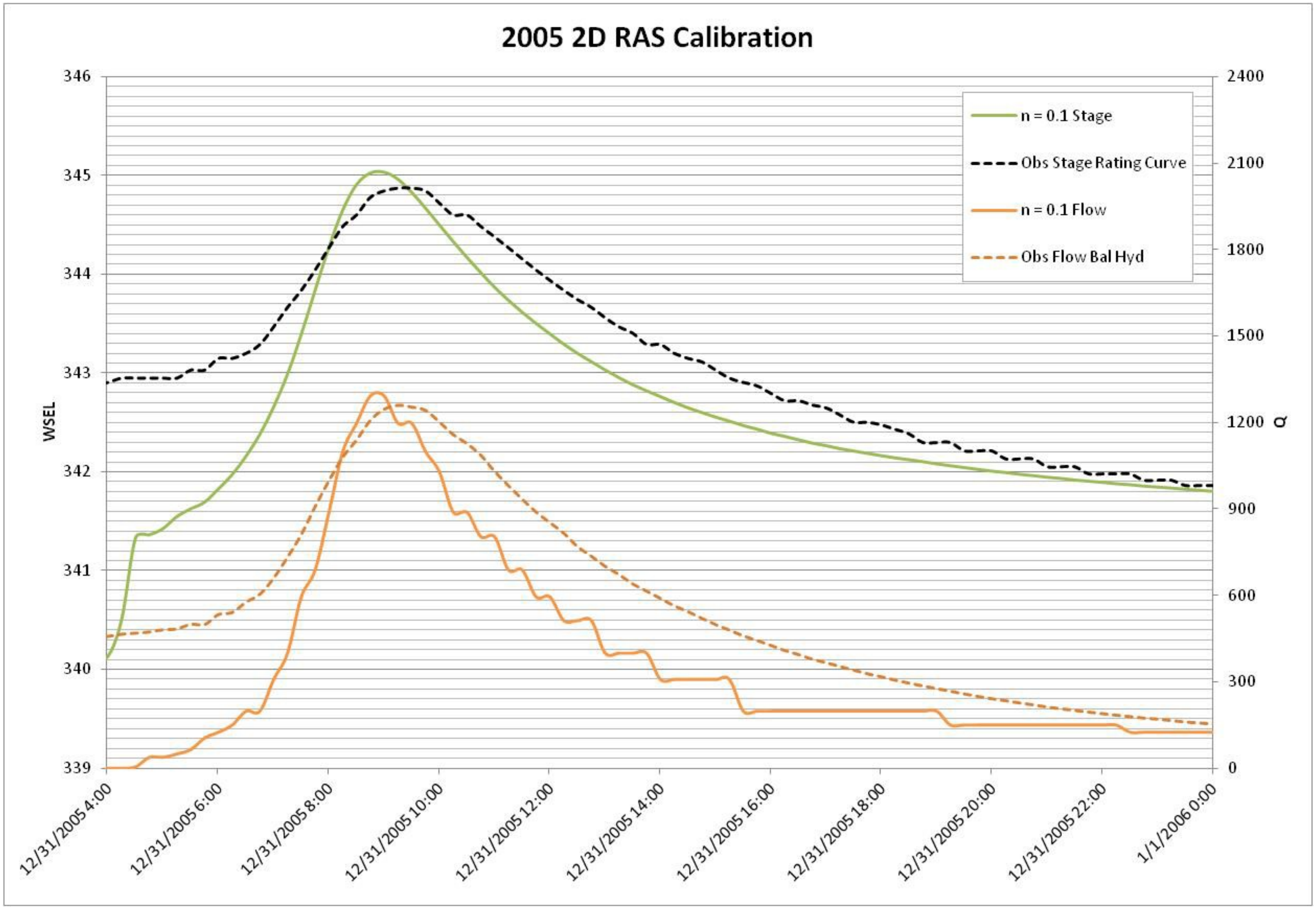


Figure 6: 2005 Searsville 2D Model Calibration

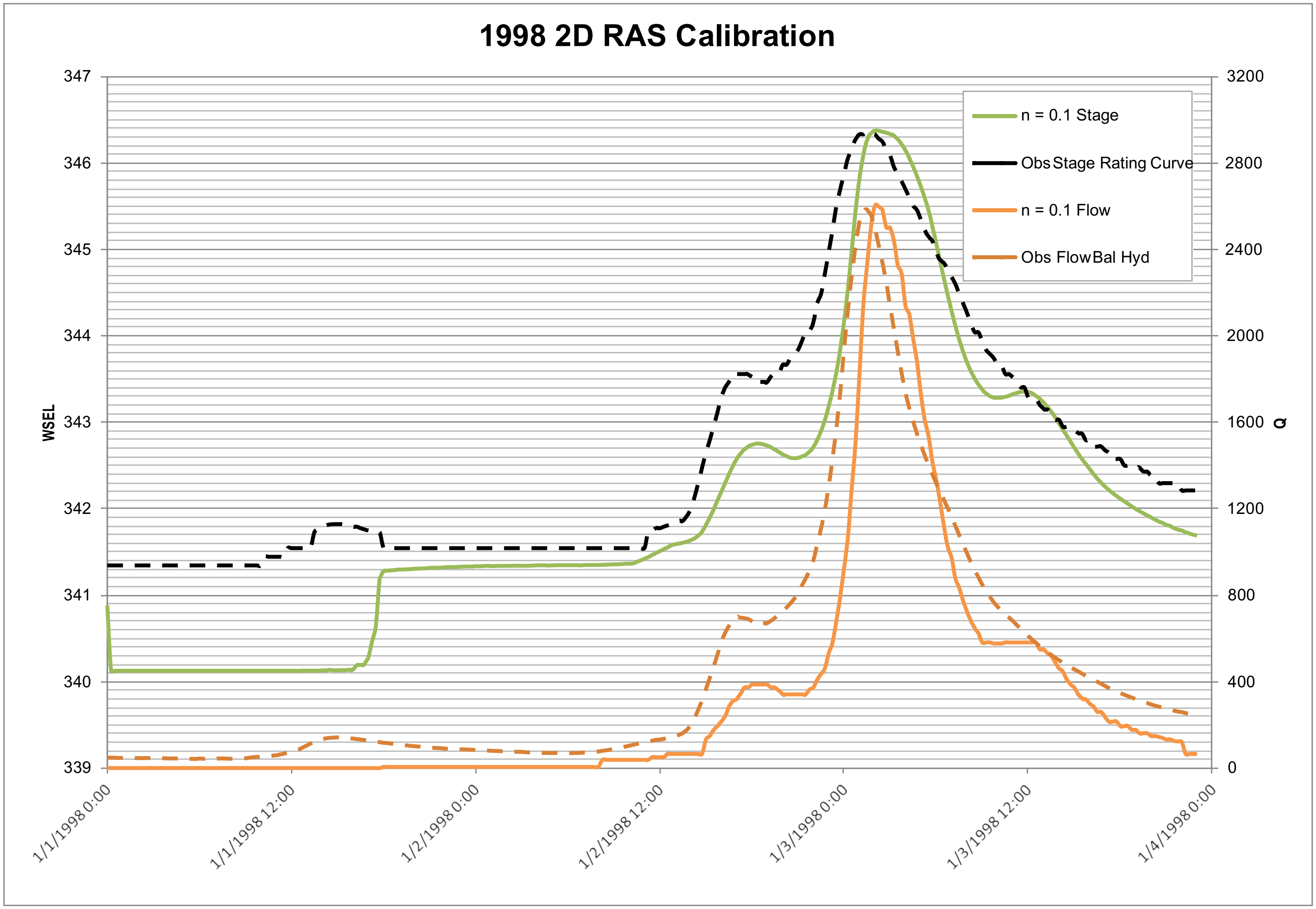


Figure 7: 1998 Searsville 2D Model Calibration

3. MODEL CALIBRATION AND VERIFICATION

3.1. STREAM GAGES

Several stream gages operated by Balance Hydrology (Stanford) have been installed recently on the upstream tributaries of San Francisquito Creek, but data availability for storm events is spotty. There is also a USGS gage, #11164500, near Stanford that has 74 annual maximum observations over 83 years. This gage will be used to determine the flood frequency analysis (FFA).

3.2. CALIBRATION PROCEDURE

The San Francisquito Creek HEC-HMS hydrology model was calibrated and verified to observed stream gage data by using historical gage adjusted rainfall radar data that has been calibrated to observed rain gage data. In short, observed rainfall data was used as input into the hydrologic model for several historic storm events, and the output values compared to observed stream gage data for the same event.

Calibration and verification was done by using the USGS gage recorded flows as the primary gage, since it is considered the most reliable. Gages operated by Balance upstream of the USGS gage were considered suspect for some events. The observed data from these gages were used when evidence did not prove them suspect. However, the observed data was still used as a general reference for suspect events to determine peak timing. Five sub-areas were categorized based on gage catch points to facilitate discussion of model calibration results. The general flowchart is shown in Figure 7.

- Searsville, which includes the area tributary to Searsville Lake and Dam.
- Bear, which includes all of Bear Creek and tributaries up to its confluence to San Francisquito Creek below the Dam.
- Los Trancos, which includes all of Los Trancos Creek and tributaries up to the stream flow gage.
- USGS, which includes all the drainage area from Searsville, Bear, and Los Trancos, to the USGS stream gage
- Urban, which includes the area between the USGS stream gage and the San Francisco Bay.

A map of the five sub-areas, along with the locations of flow measurement stations can be seen in Figure 12.

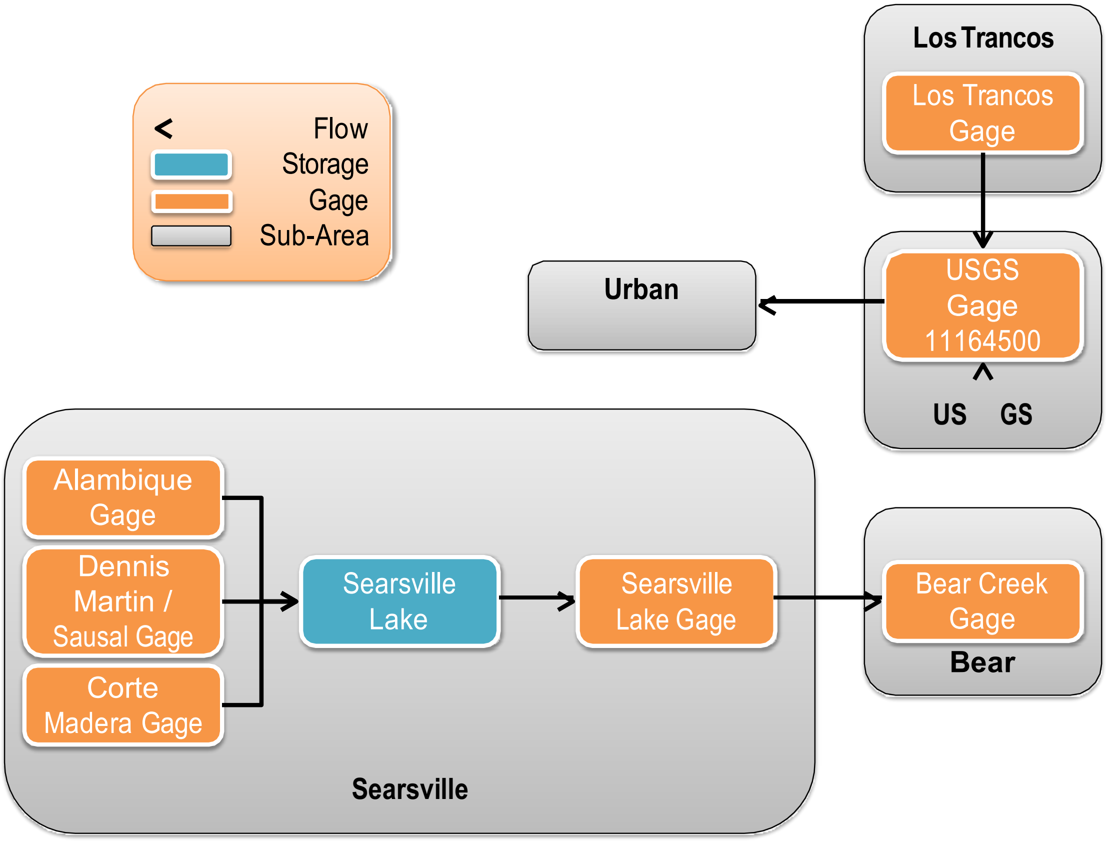


Figure 8: Calibration Sub-Areas

3.3. STREAM GAGE ERRORS

Recorded stream gage data in 2010 and 2011 from Balance are suspiciously low compared to flows measured at the downstream USGS gage. Almost all the runoff is contributed by the majority of the upstream hill watershed, which also gets the most rain. In 2012 and 2006, the total of all the Balance gages was very close to the USGS gage, as shown in Figure 8 and Figure 9. However, in 2011 and 2010, a large amount of flow is missing, shown in Figure 10 and Figure 11. It is likely that there was error in flow measurements from Balance under these circumstances. Therefore, observed Balance stream gate data points for 2011 and 2010 will be used for reference only.

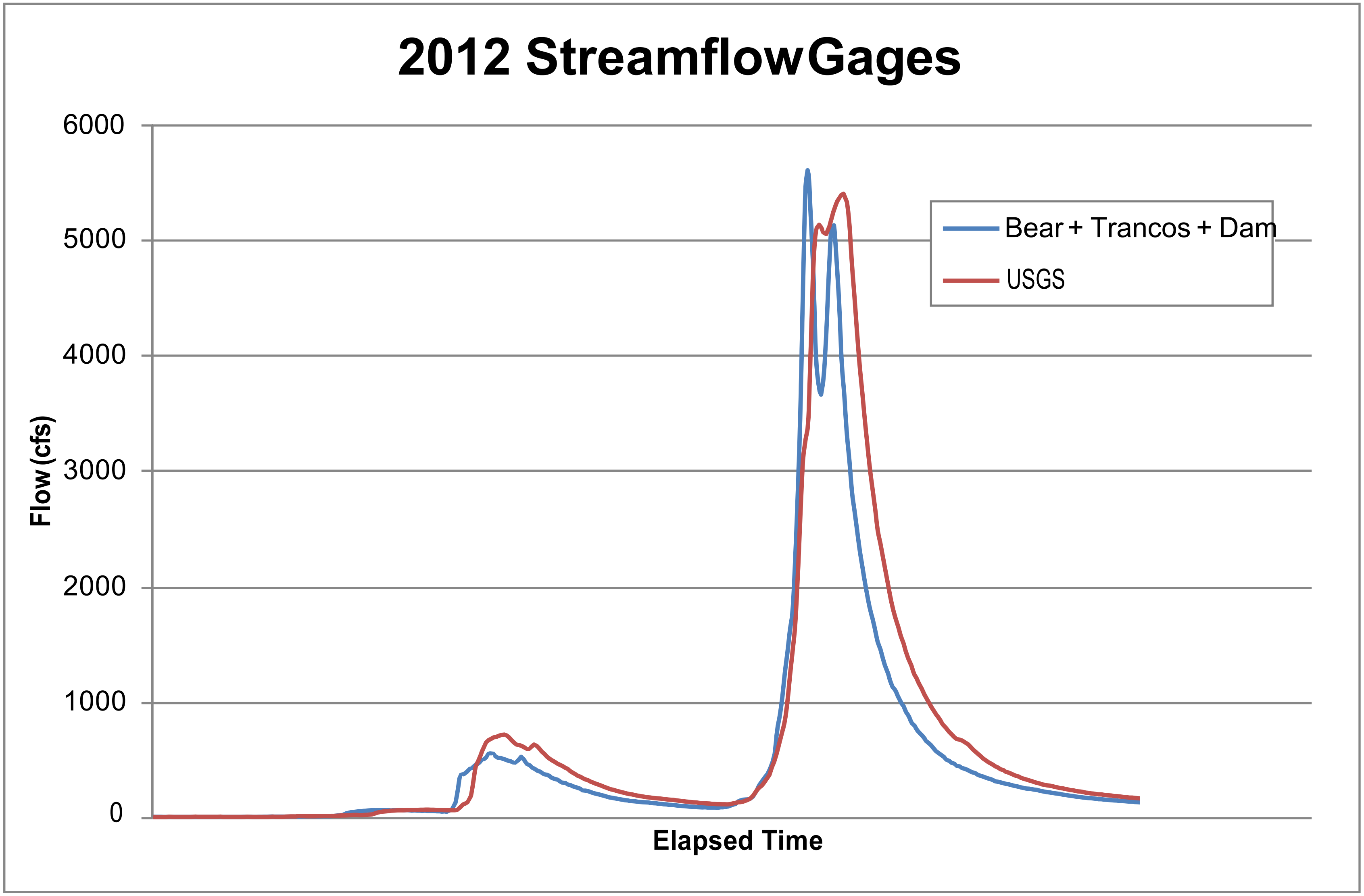


Figure 9: 2012 Streamflow Gage Comparison

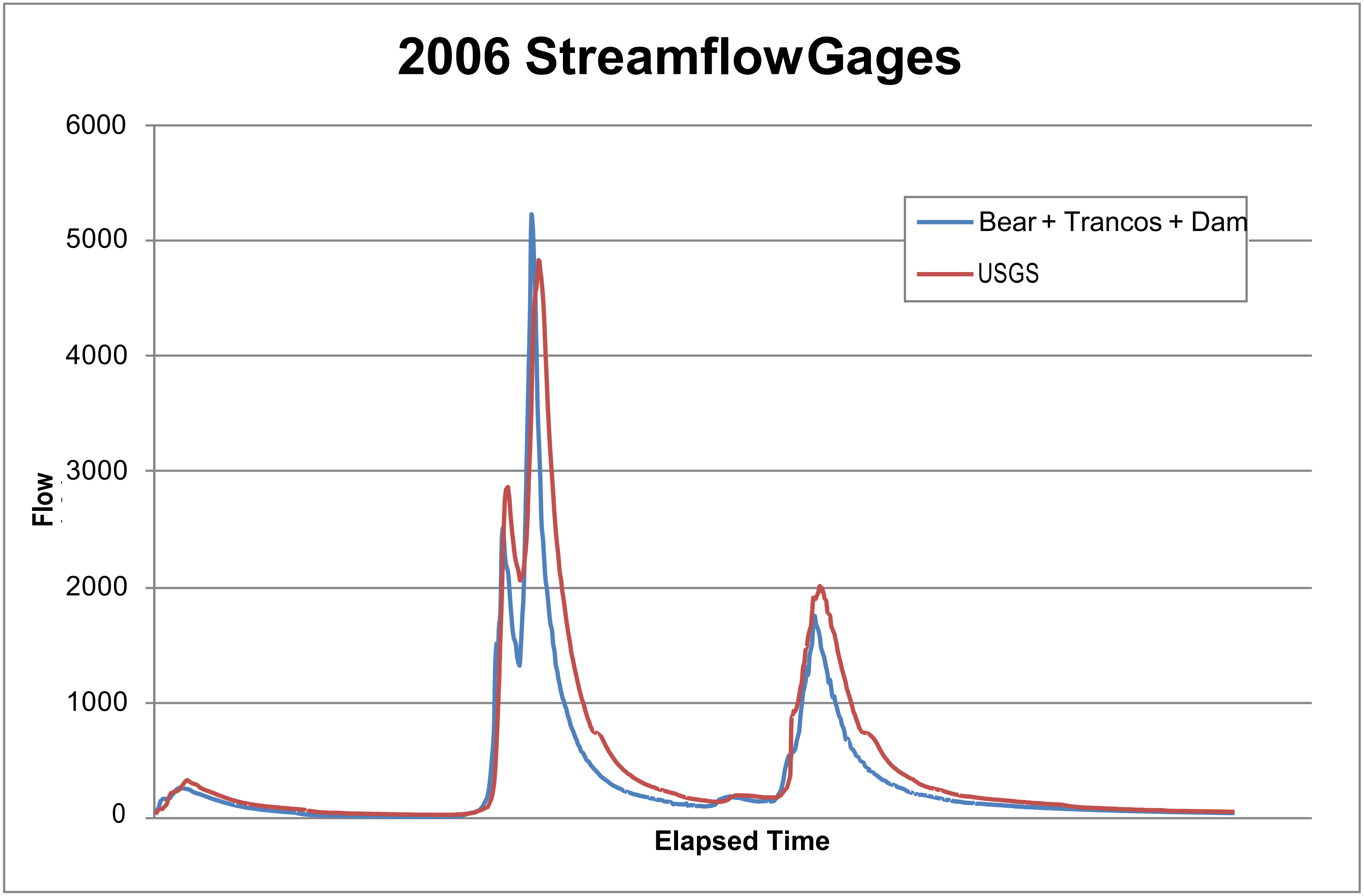


Figure 10: 2006 Streamflow Gage Comparison

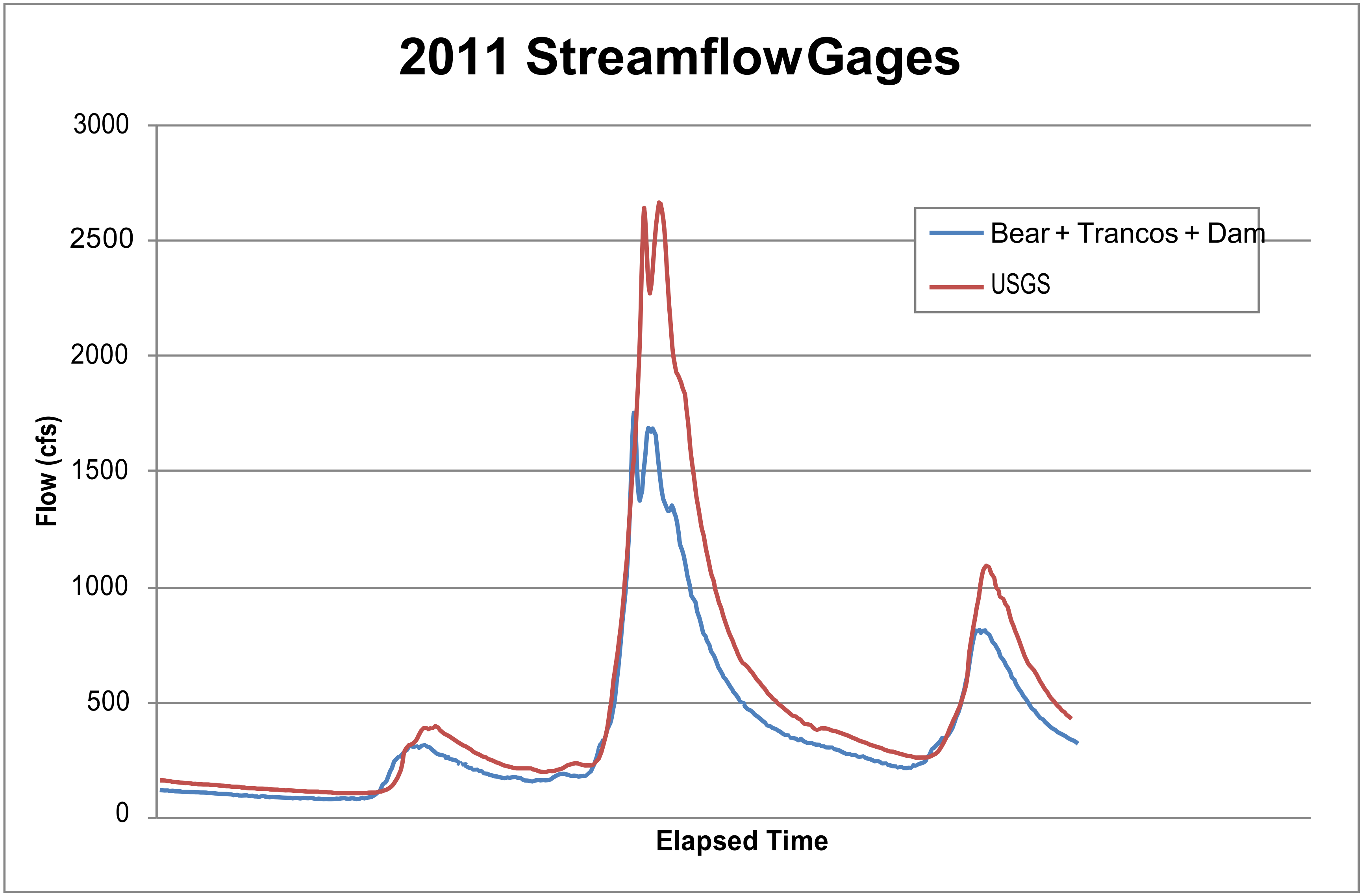


Figure 11: 2011 Streamflow Gage Comparison

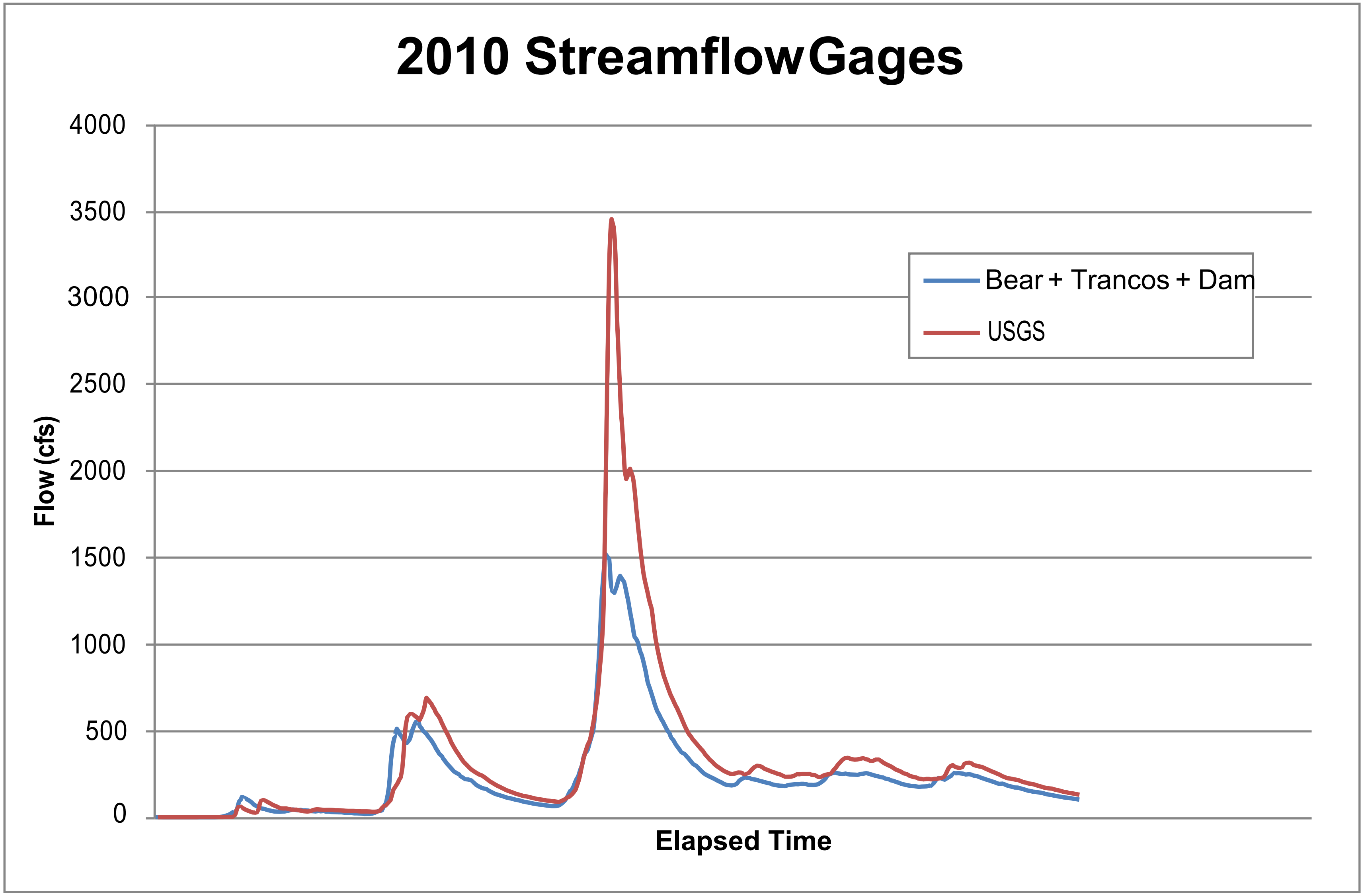


Figure 12: 2010 Streamflow Gage Comparison

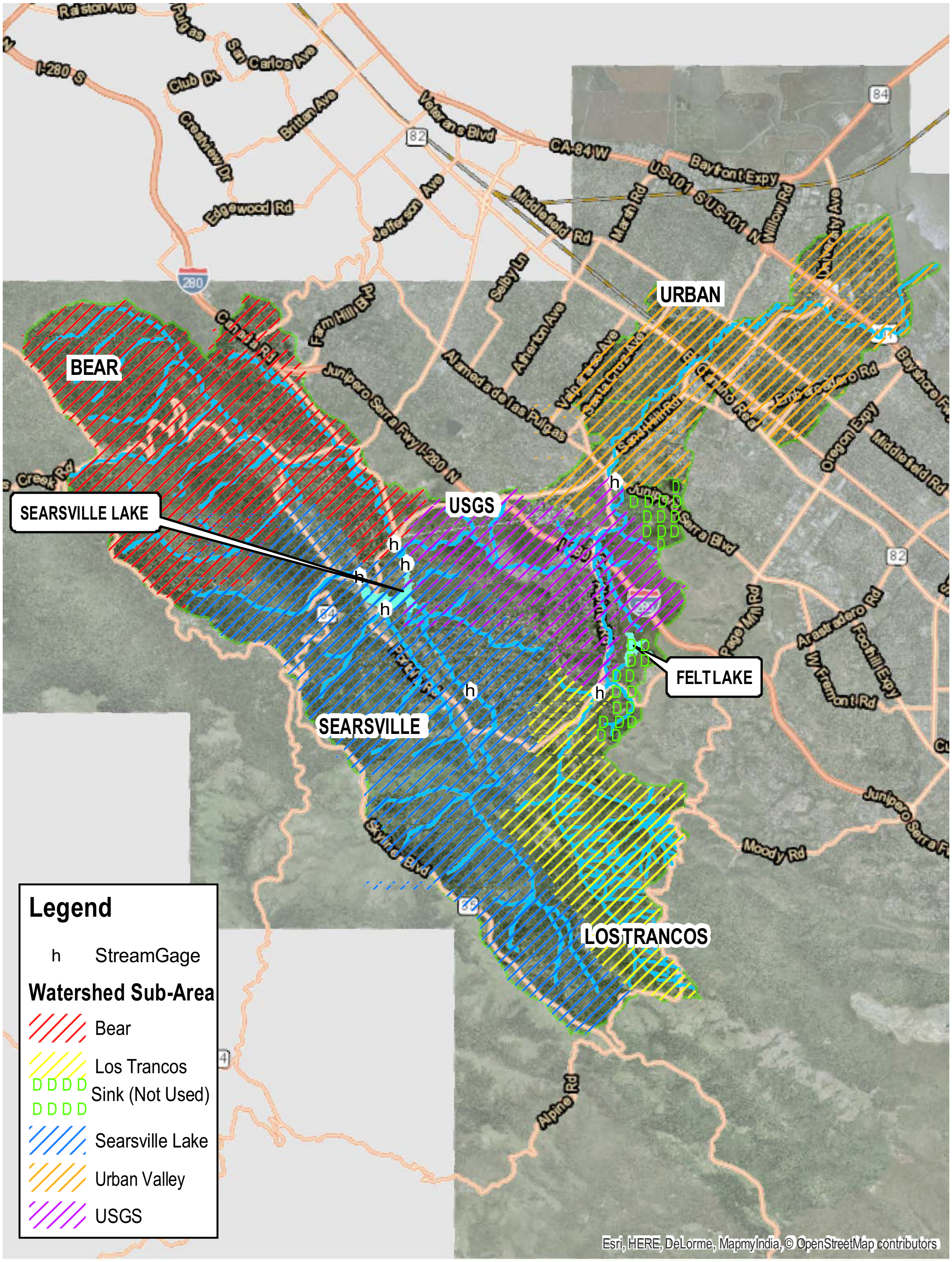


Figure 13: Basin Map

4. CALIBRATION AND VERIFICATION RESULTS

4.1. 02 FEBRUARY 1998

Table 2: February 1998 Model Calibration Parameters

Sub-Area	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
Bear	2.25	Q25	0.5
Searsville	1.75	Q10	0.5
Los Trancos	2.0	Q25	0.5
USGS	2.0	Q25	0.5
Urban	2.0	Q25	0.5

**As described in Section 2.3.5 – numbers are based of observed flows at gaging points.*

Three gage locations were in operation for this storm event: USGS, Searsville Lake, and Los Trancos. Since Searsville Lake has already been calibrated, and no gages were in operation upstream of the dam, the observed gage outflow from the dam will be used as input for this calibration event. A 1.75 AMC value for Searsville with a slightly lower time of concentration flow matched well for the 2D model calibration. Flow at the USGS gage matched well.

The peak timing for the Los Trancos gage is slightly later for the modeled result. However, this gage experienced backwater from the downstream fish ladder according to notes by Balance Hydrology. Therefore, this reading serves only as a reference.

The peak timing for the USGS gage is also slightly later for the modeled result and there is slightly less volume in the front end of the hydrograph. However, the calibration results are acceptable. The Bear sub-area antecedent moisture condition (AMC) was increased slightly to 2.25 to bring flows at the USGS gage up to observed values.

Observed flows are in black. Modeled flows are shown in blue. A reference rainfall pattern over Searsville Lake is included under the hydrographs.

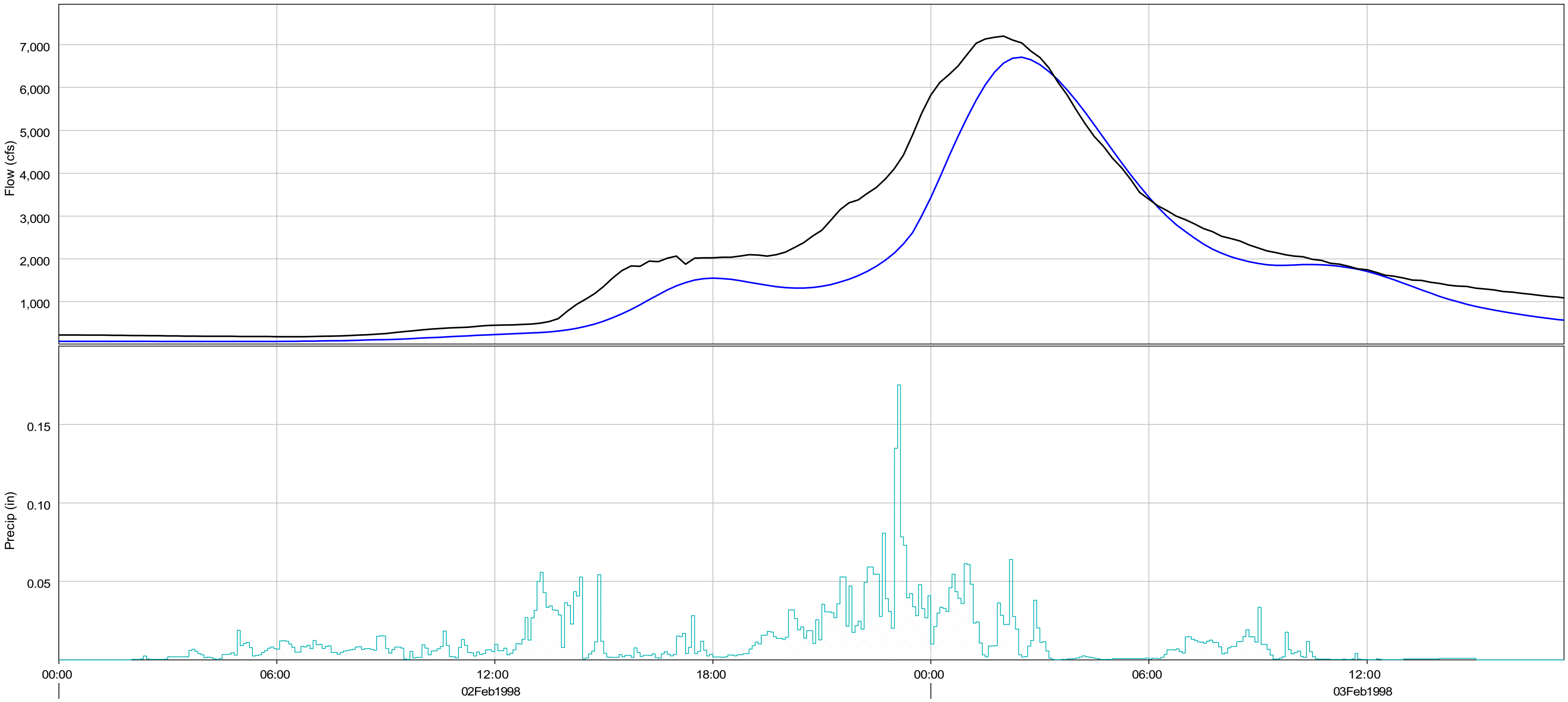


Figure 14: USGS – February 1998

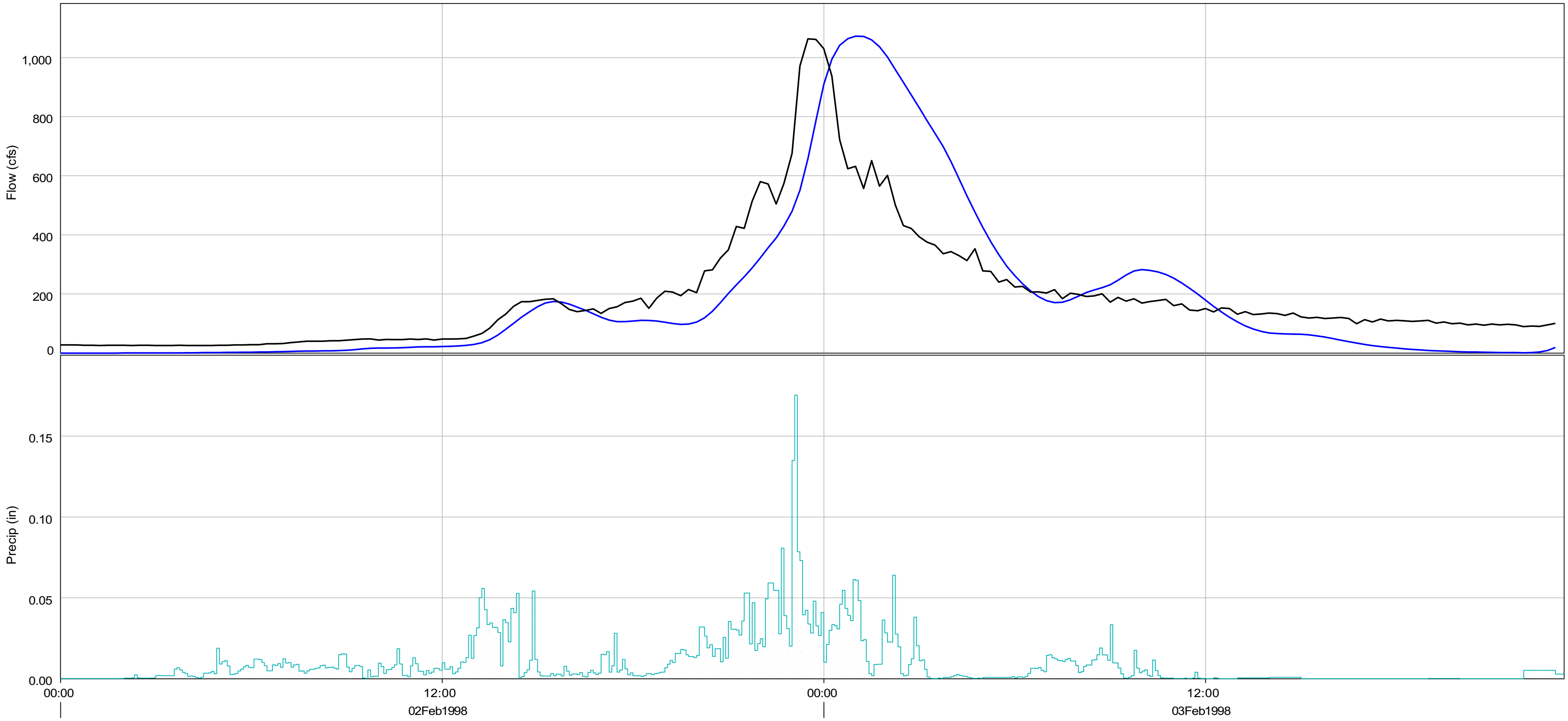


Figure 15: Los Trancos - February 1998

NOTE: *Los Trancos stream flow gage measurements experienced observed backwater from a downstream fish ladder.*

4.2. 12 FEBRUARY 2000

Table 3: February 2000 Model Calibration Parameters

Sub-Area	AMC	Time of Concentration Q	Storage Coefficient (R) Ratio
Bear	2.75	Q10	0.5
Searsville	2.0	Q10	0.5
Los Trancos	1.75	Q5	0.5
USGS	2.0	Q10	0.5
Urban	2.0	Q10	0.5

**As described in Section 2.3.5 – numbers are based of observed flows at gaging points.*

Three gage locations were in operation for this storm event: USGS, Bear, and Los Trancos. Searsville Lake observed outflow was not available for this date so the 2D hydraulic model was used to supplement. The hydrologic model was run with the parameters shown above, and the output hydrographs upstream of Searsville Lake were used as flow inputs into the 2D model. The resulting 2D spill from Searsville Dam was used as input into the hydrologic model to complete the calibration.

The Bear gage required a very high AMC value of 2.75 to reach the flows observed from the gage. It is suspected that poor rainfall data is to blame. Downstream, observed gage data was used as input. Los Trancos Creek experienced little flow comparatively.

The recorded USGS gage hydrograph has more volume and peak flow than the model. Since most of the flow is controlled by the inputs of Bear, Searsville, and Los Trancos, it is suspected that a combination of low rainfall data affecting runoff volume (evidenced by Bear) and observed stream gage data that is slightly off. Overall, the timing and peak still match well.

Observed flows are in black. Modeled flows are shown in blue. A reference rainfall pattern over Searsville Lake is included under the hydrographs.

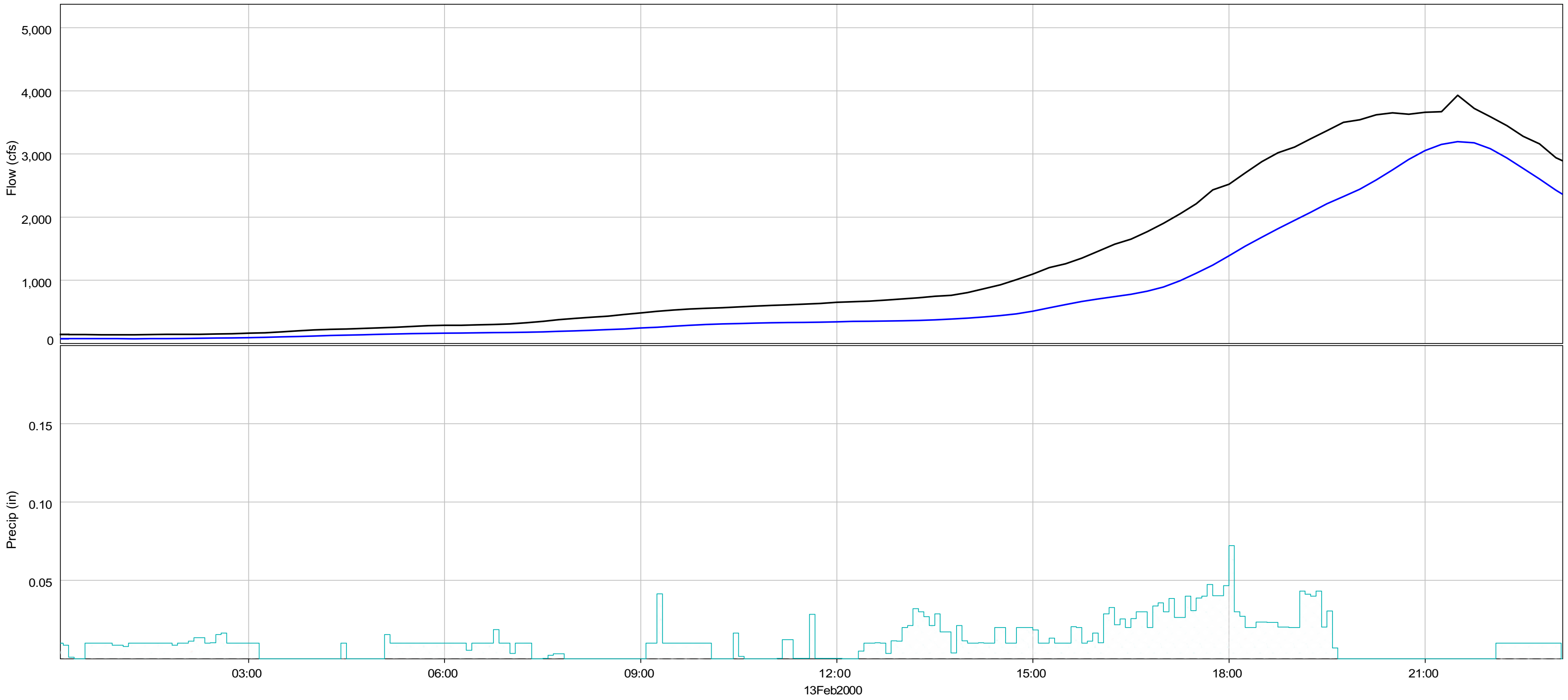


Figure 16: USGS – February 2000

NOTE: *Bear Creek and Los Trancos observed flow data were used as inputs in determining flow at USGS.*

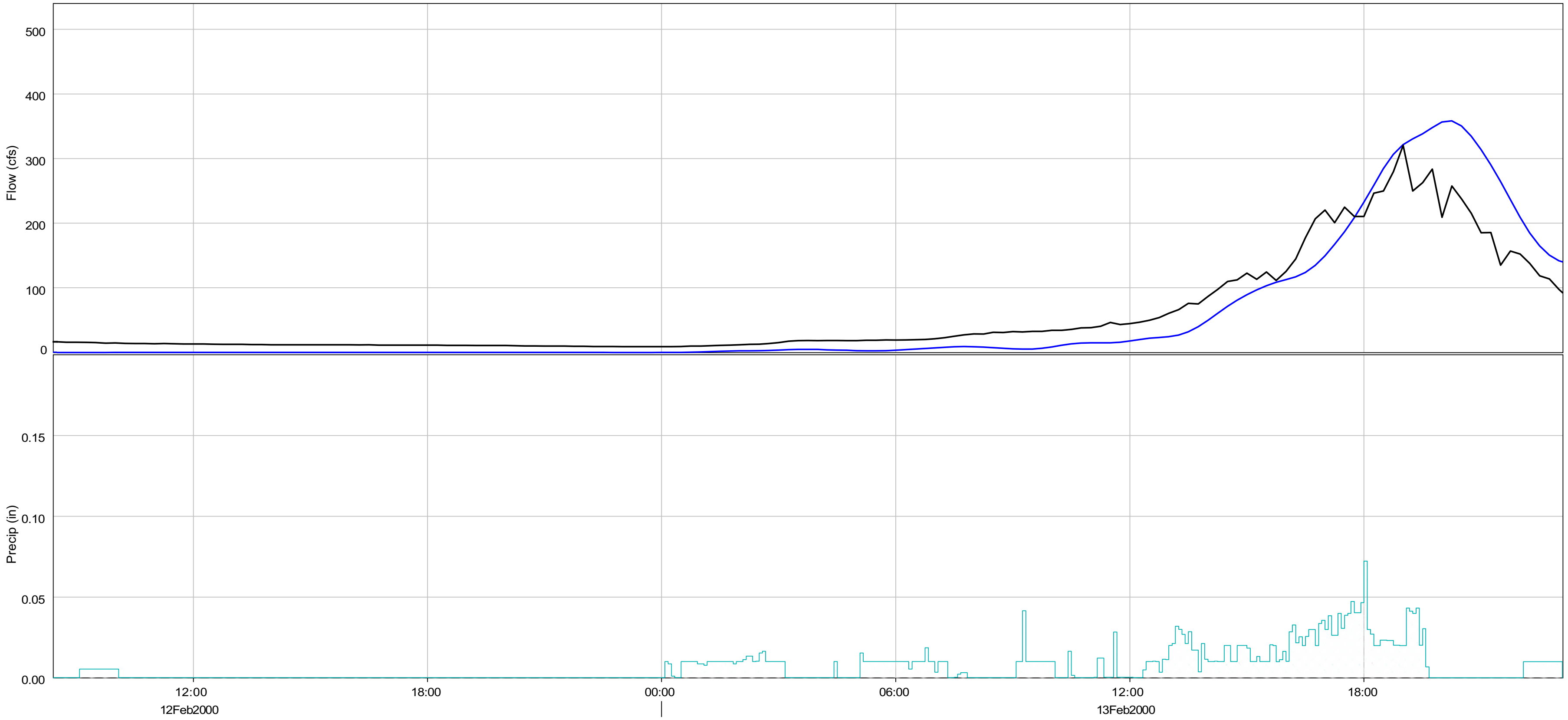


Figure 17: Los Trancos – February 2000

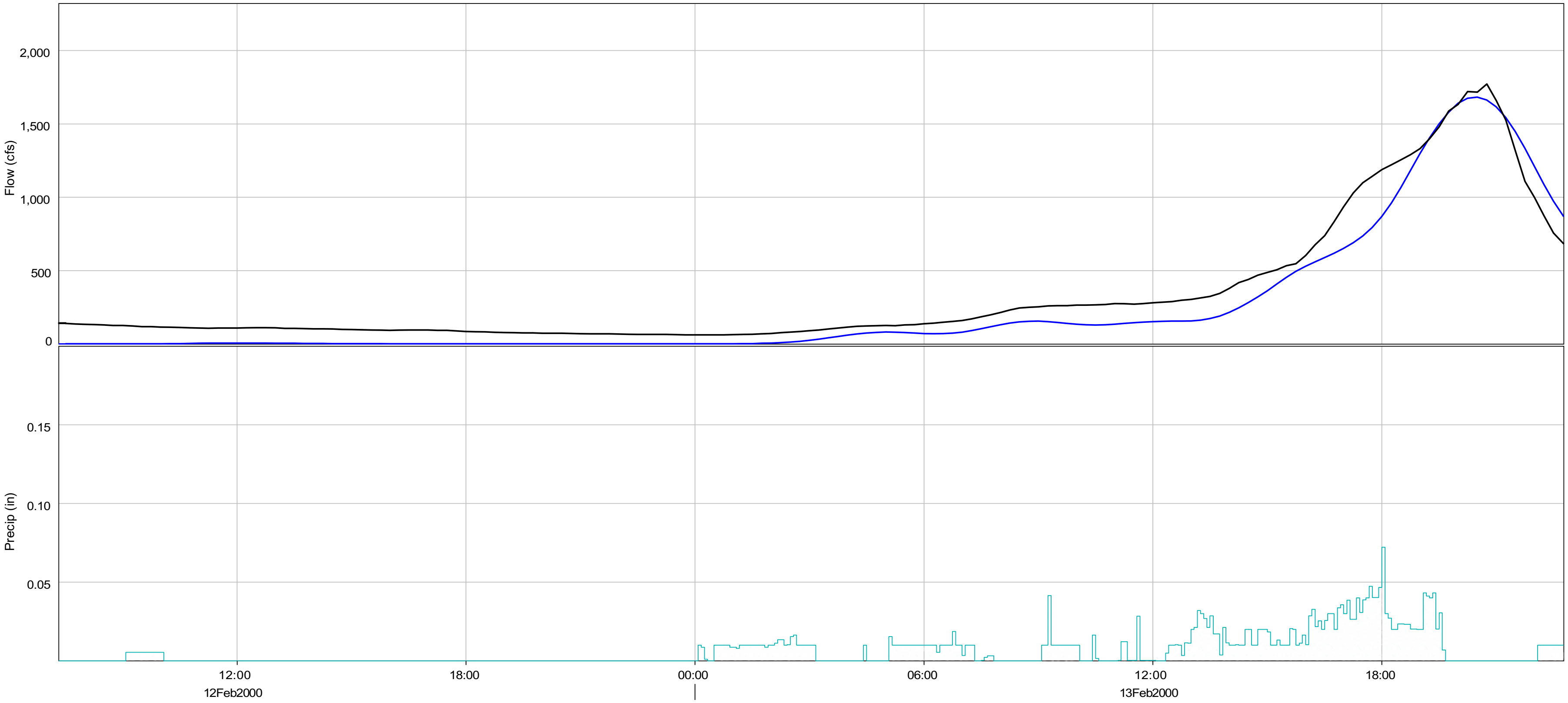


Figure 18: Bear – February 2000

4.3. 18 JANUARY 2010

Table 4: January 2010 Model Calibration Parameters

Sub-Area	AMC	Time of Concentration Q	Storage Coefficient (R) Ratio
Bear	2.0	Q10	0.5
Searsville	1.75	Q10	0.5
Los Trancos	2.0	Q10	0.5
USGS	2.0	Q10	0.5
Urban	2.0	Q10	0.5

**As described in Section 2.3.5 – numbers are based of observed flows at gaging points.*

Five gage locations were in operation for this storm event: USGS, Searsville Dam, Bear, Corte Madera, and Los Trancos. From previous discussion about possible gage errors stemming from Bear and Los Trancos, the observed flow from these gages were not used as inputs. Downstream reference points relied solely on the model.

Using the Searsville recorded outflow, combined with Bear and Los Trancos watersheds at an AMC of 2.0, the modeled flow at the USGS gage matched well with the observed data.
For the Searsville watershed, the only operational gage upstream was Corte Madera. The catch point in the model is downstream of the gage, and therefore a higher modeled flow would be expected. An AMC value of 1.75 computed a flow that is slightly larger than recorded.

Observed flows are in black. Modeled flows are shown in blue. A reference rainfall pattern over Searsville Lake is included under the hydrographs.

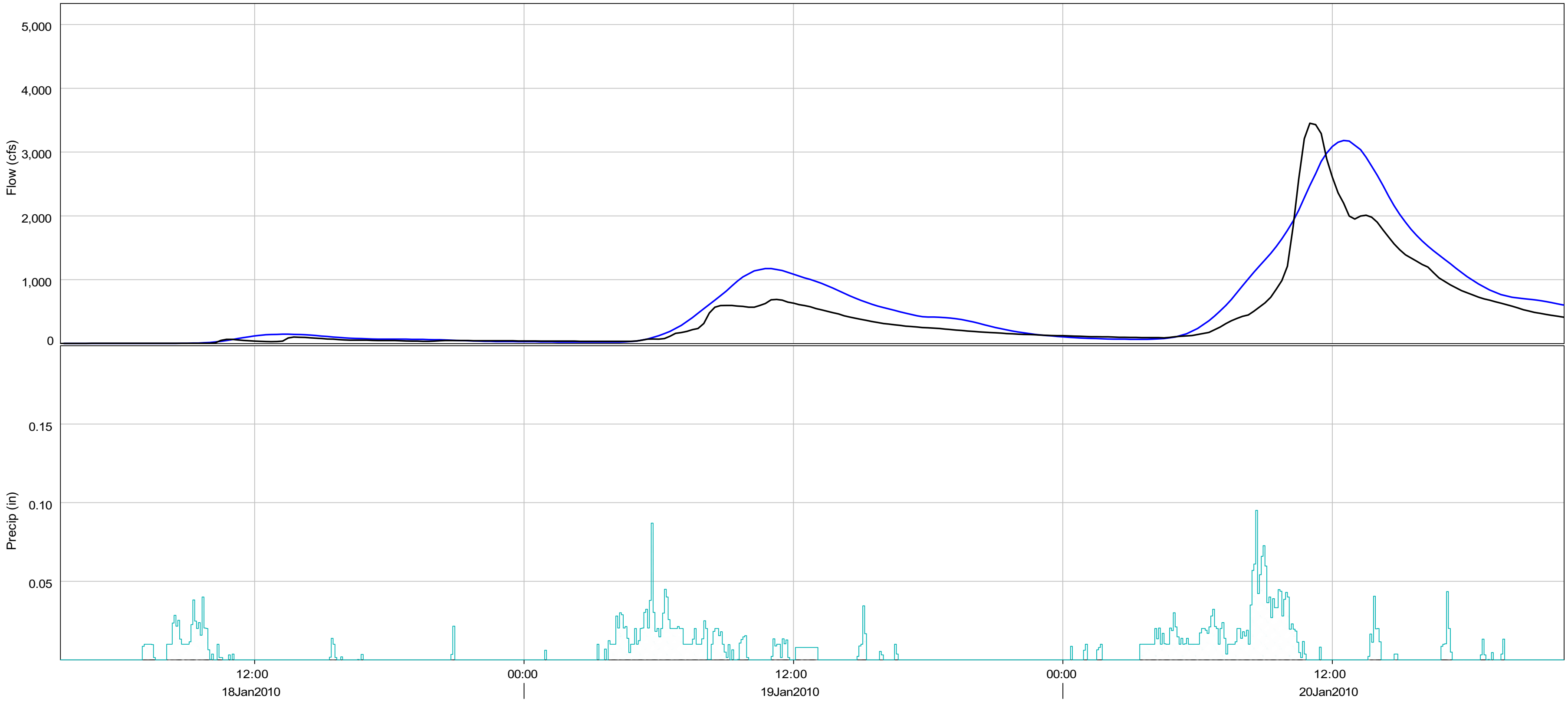


Figure 19: USGS – January 2010

NOTE: *Bear Creek and Los Trancos observed flow data were removed and not used as inputs in determining flow at USGS.*

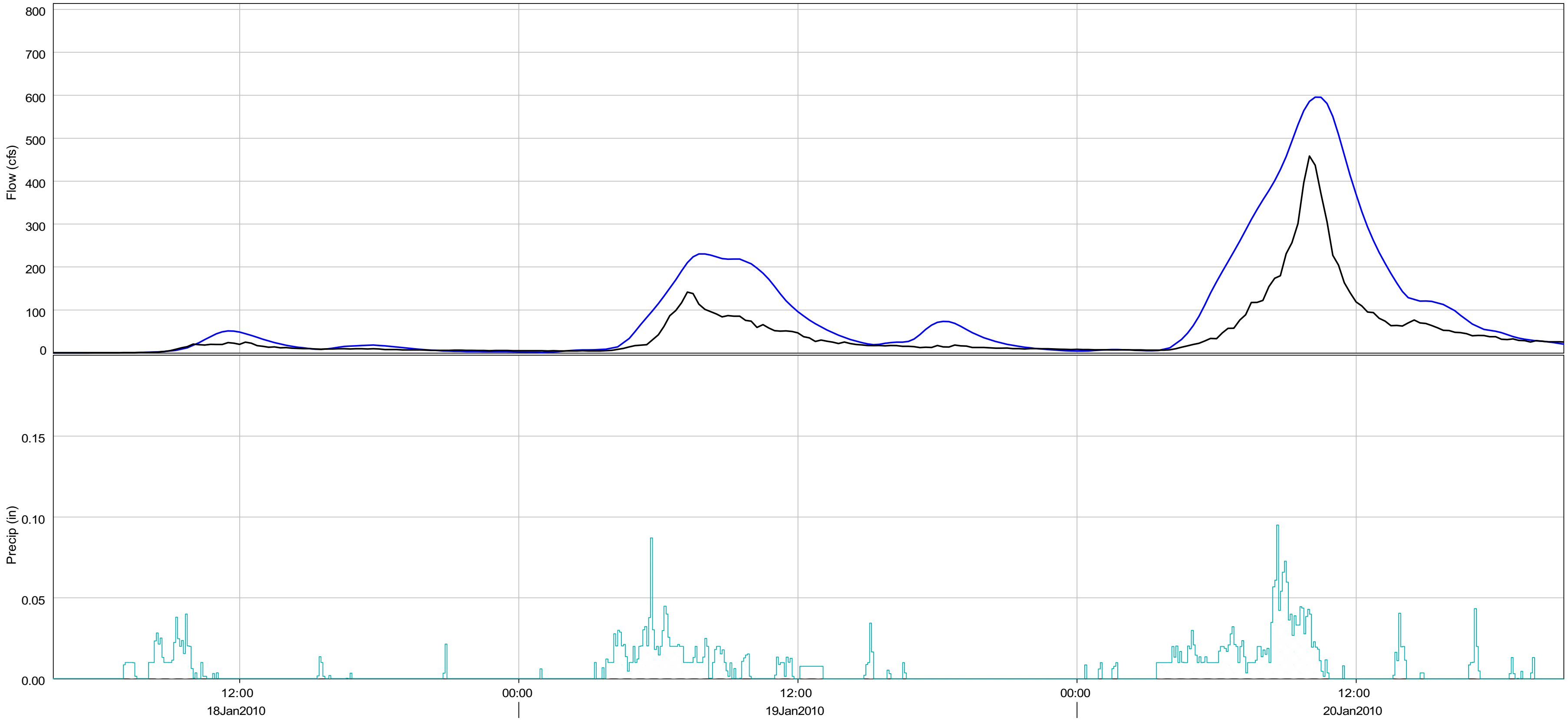


Figure 20: Los Trancos – January 2010

NOTE: *Los Trancos stream flow gage measurements are suspected to be low. Observed data should be used as a rough reference.*

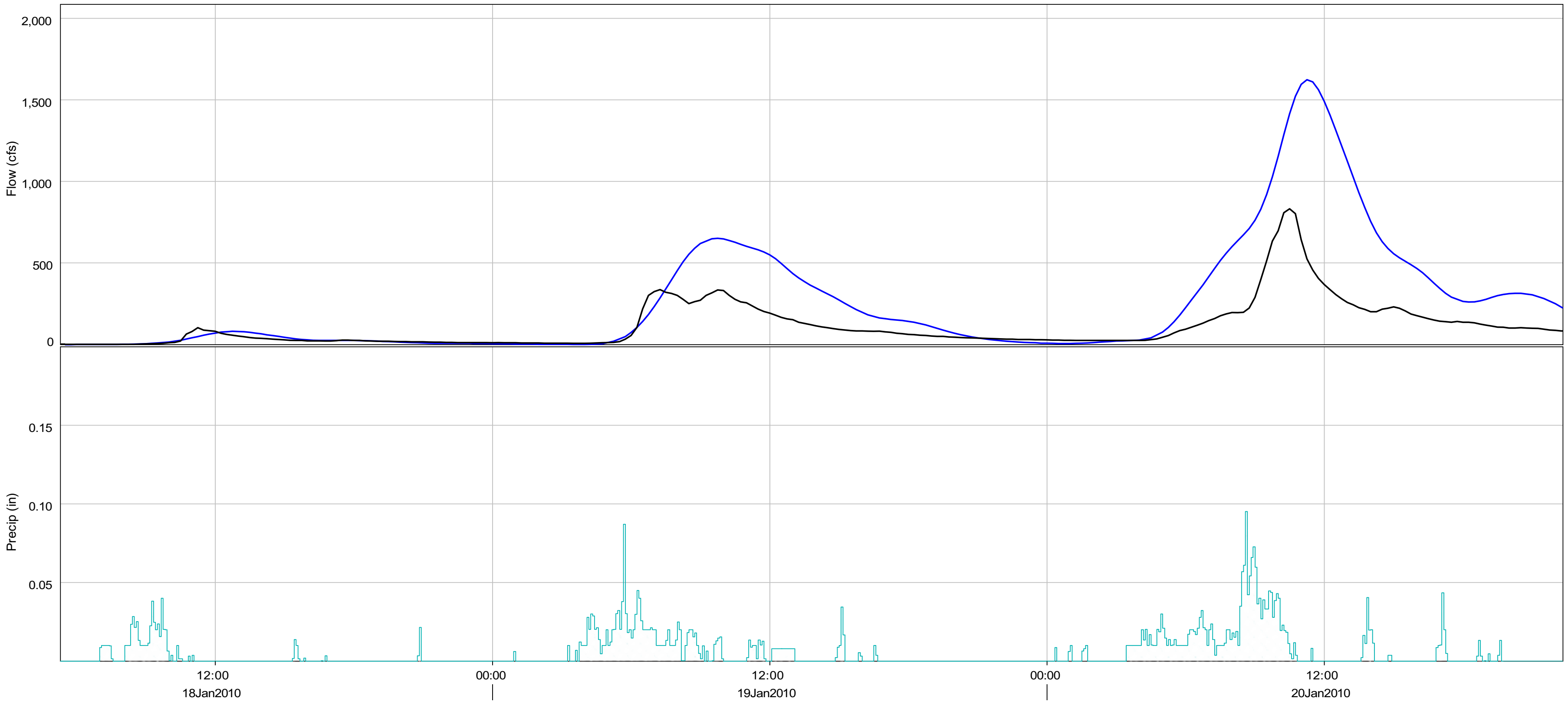
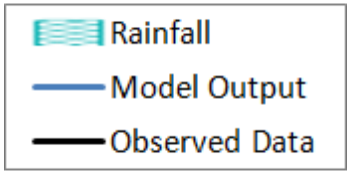


Figure 21: Bear – January 2010

NOTE: *Bear stream flow gage measurements are suspected to be low. Observed data should be used as a rough reference.*



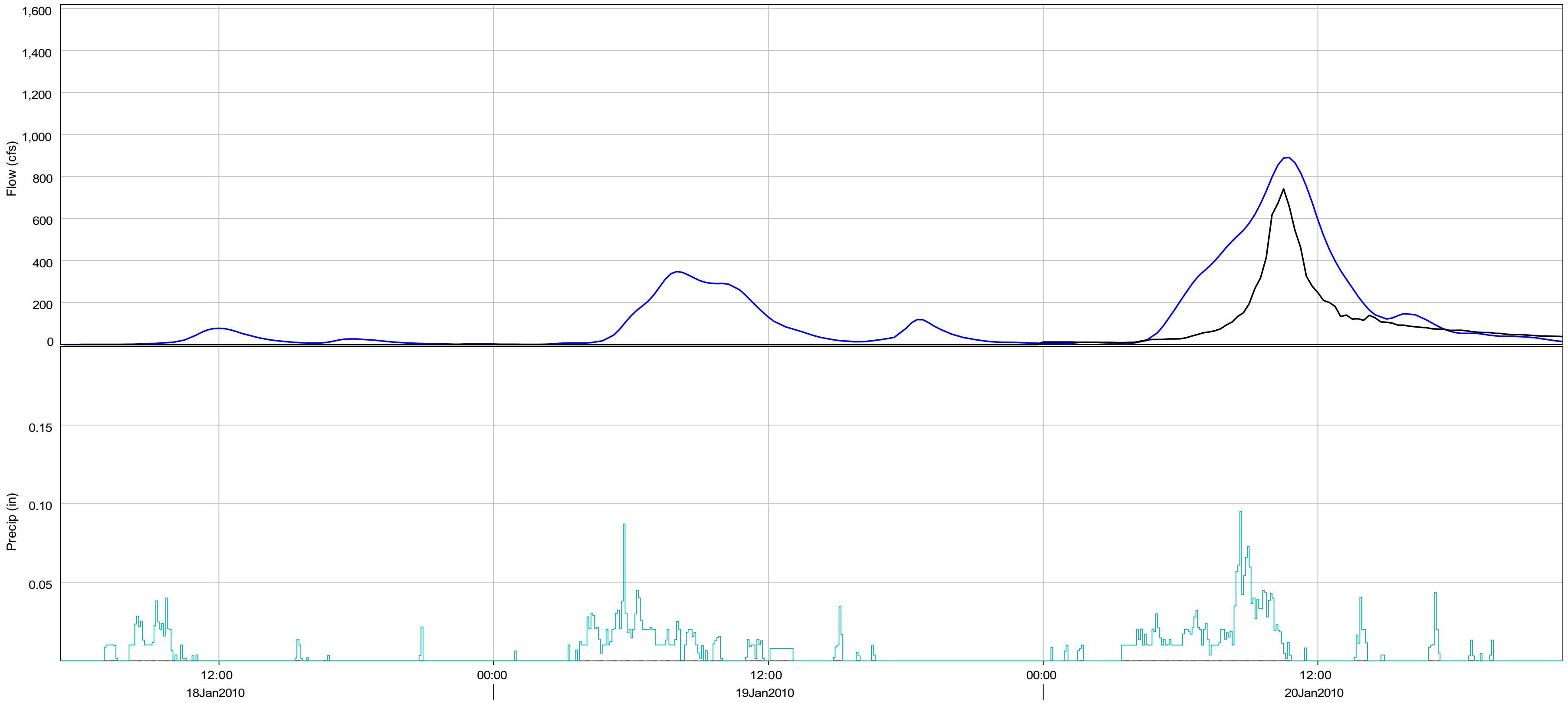


Figure 22: Corte Madera – January 2010

NOTE: *Stream gage located upstream of model catch point. Observed flow should be slightly lower than the model results.*

4.4. 22 MARCH 2011

Table 5: March 2011 Model Calibration Parameters

Sub-Area	AMC	Time of Concentration Q	Storage Coefficient (R) Ratio
Bear	2.0	Q10	0.5
Searsville	1.75	Q10	0.5
Los Trancos	2.0	Q10	0.5
USGS	2.0	Q10	0.5
Urban	2.0	Q10	0.5

**As described in Section 2.3.5 – numbers are based of observed flows at gaging points.*

Five gage locations were in operation for this storm event: USGS, Searsville Dam, Bear, Corte Madera, and Los Trancos. Similar to the 2010 calibration, there are possible gage errors stemming from Bear and Los Trancos. Therefore, the observed flows from these gages were not used as inputs. Downstream reference points relied solely on the model. However, Los Trancos gage matched perfectly with modeled output without any effort, which puts suspicion on the Bear gage.

Using the Searsville outflow, combined with Bear and Los Trancos watersheds at AMC 2.0, the modeled flow at the USGS gage matched very well with the observed data.

For the Searsville watershed, the only operational gage upstream was Corte Madera. The catch point in the model is downstream of the gage, and therefore a higher modeled flow would be expected. An AMC value of 1.75 computed a flow that is slightly larger than observed. Observed flows are in black. Modeled flows are shown in blue. A reference rainfall pattern over Searsville Lake is included under the hydrographs.

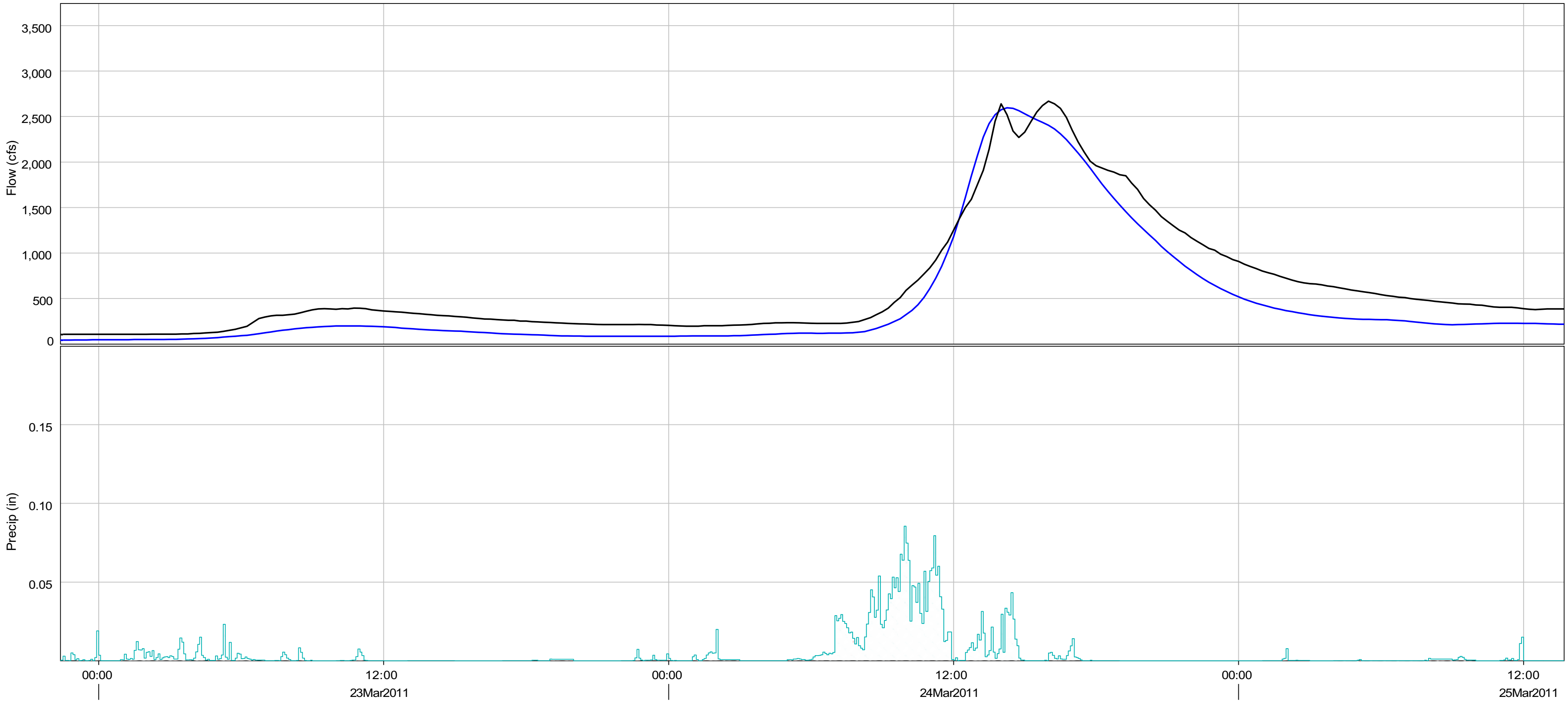


Figure 23: USGS – March 2011

NOTE: *Bear Creek and Los Trancos observed flow data were removed and not used as inputs in determining flow at USGS.*

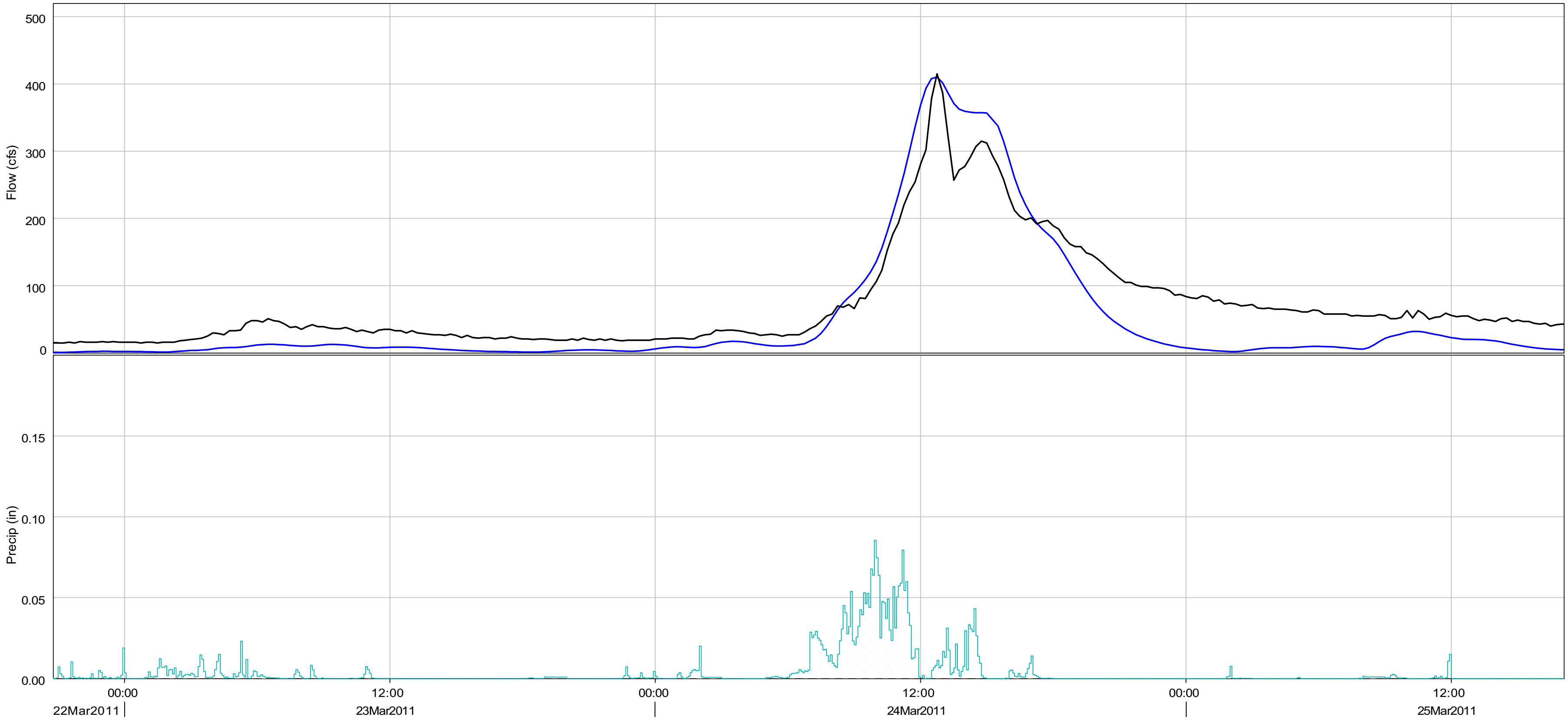
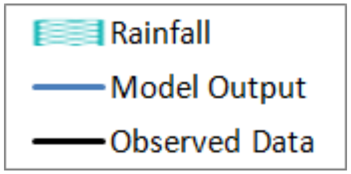


Figure 24: Los Trancos – March 2011

NOTE: *Los Trancos stream flow gage measurements might be suspect, quality unknown.*



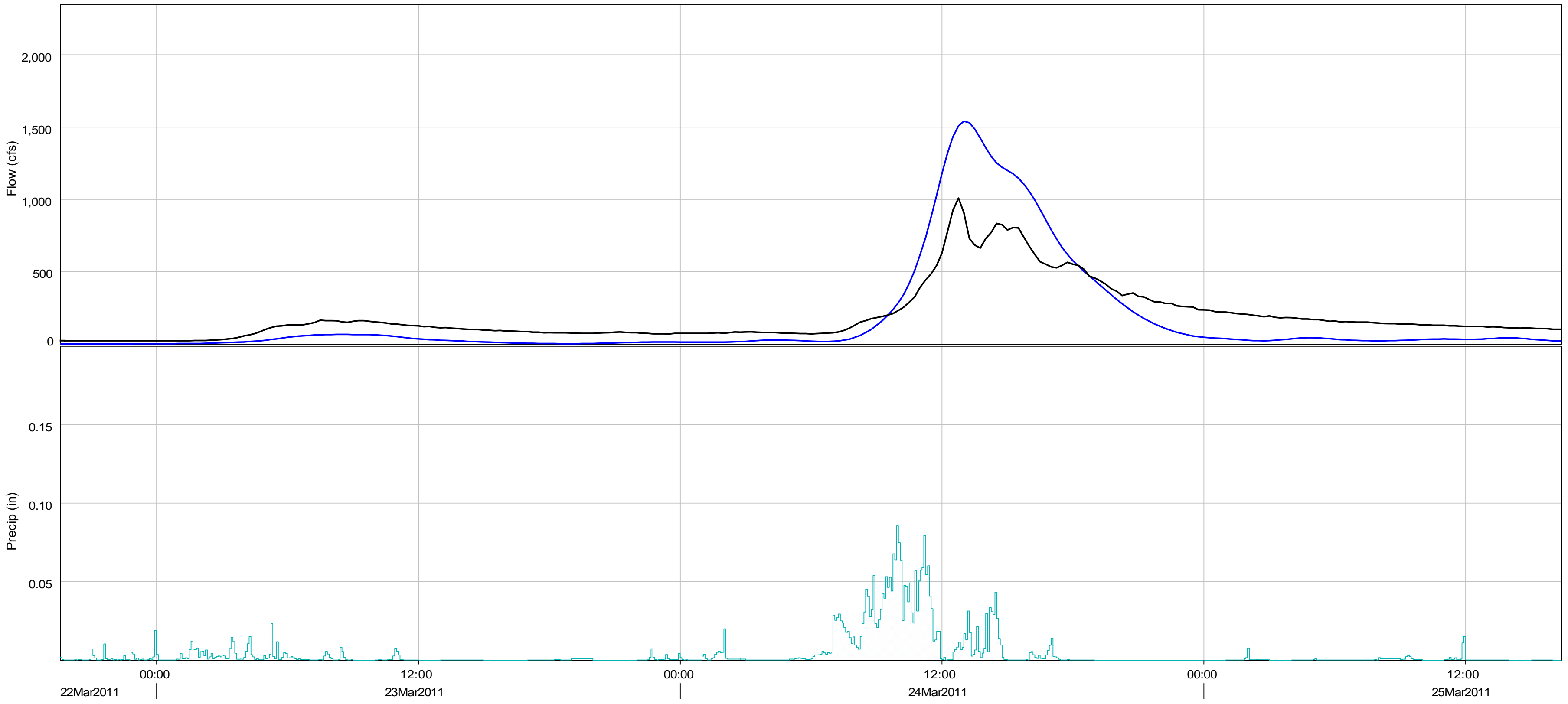
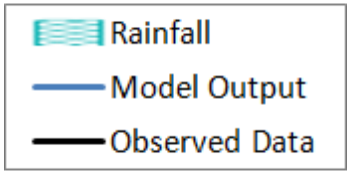


Figure 25: Bear – March 2011

NOTE: *Bear stream flow gage measurements are suspected to be low. Observed data should be used as a rough reference.*



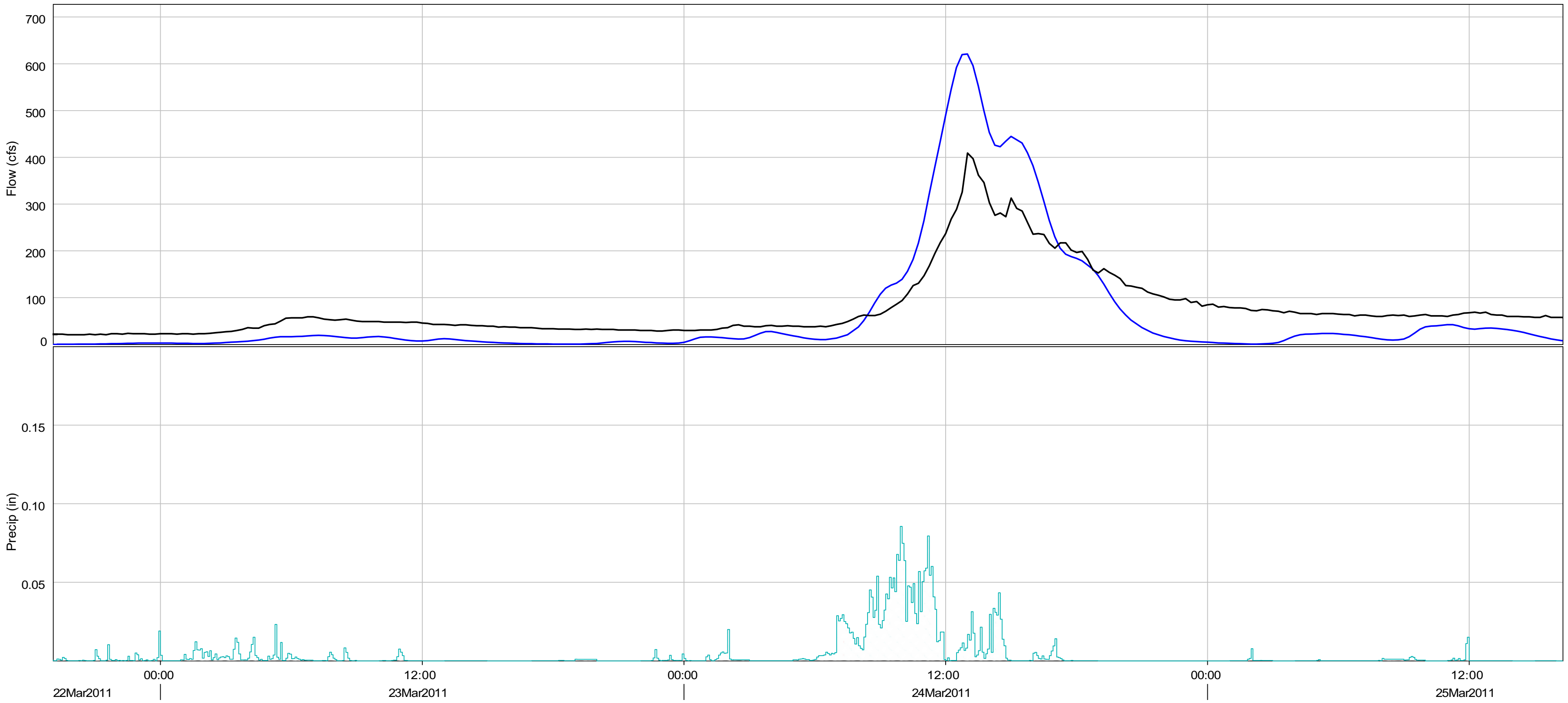
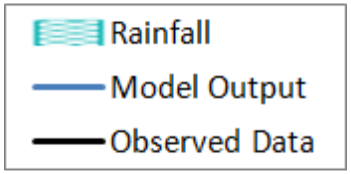


Figure 26: Corte Madera – March 2011

NOTE: *Stream gage located upstream of model catch point. Observed flow should be slightly lower than the model results.*



4.5. 21 DECEMBER 2012

Table 6: December 2012 Model Calibration Parameters

Sub-Area	AMC	Time of Concentration Q	Storage Coefficient (R) Ratio
Bear	2.5	Q200	0.5
Searsville	1.5 – 2.0	Q10	0.5
Los Trancos	1.5	Q10	0.5
USGS	2.0	Q10	0.5
Urban	2.0	Q10	0.5

**As described in Section 2.3.5 – numbers are based of observed flows at gaging points.*

Seven gage locations were in operation for this storm event: USGS, Searsville Dam, Bear, Corte Madera, Alambique, Dennis Martin/Sausal, and Los Trancos. Alambique gage experienced debris and clogged culvert issues, and therefore will only be used as reference. Alambique, Dennis Martin/Sausal, and Corte Madera gages are all upstream of Searsville Dam, and will be used to determine parameters for the Sub-Area Searsville.

For the Searsville watershed, Corte Madera sub-basins were given an AMC value of 2.0, while the rest of the northern sub-basins, including Alambique and Dennis Martin / Sausal, were given an AMC of 1.5 in the Searsville sub-area. This northern sub-area shares a boundary with Bear. It is likely that the rainfall error for Bear is also present in the northern Searsville sub-area as well.

The measured flow at the Bear Creek gage is very high, approaching a 200-year return period when using the USGS gage as a reference. AMC was set at 2.5, but the model could not reproduce the flows that were measured. Erroneous rainfall data is suspected, as a high stream flow at Bear is required to produce the flows seen at USGS. In addition, rainfall discrepancies are seen for sub-basins at higher elevations. This error probably stems from a District rain gage malfunction during this storm, which removed an important calibration point for the radar data. However, there is also a possibility of stream flow gage error, as the peak lasts for much longer, and the volume much higher at the USGS gage.

Using the Searsville outflow, combined with Bear and Los Trancos at an AMC 2.0, the modeled flow at the USGS gage matches the initial rising peak, but is not able to sustain the peak for very long.

Los Trancos is given an AMC of 1.5, and modeled flows are slightly higher than observed. Observed flows are in black. Modeled flows are shown in blue. A reference rainfall pattern over Searsville Lake is included under the hydrographs.

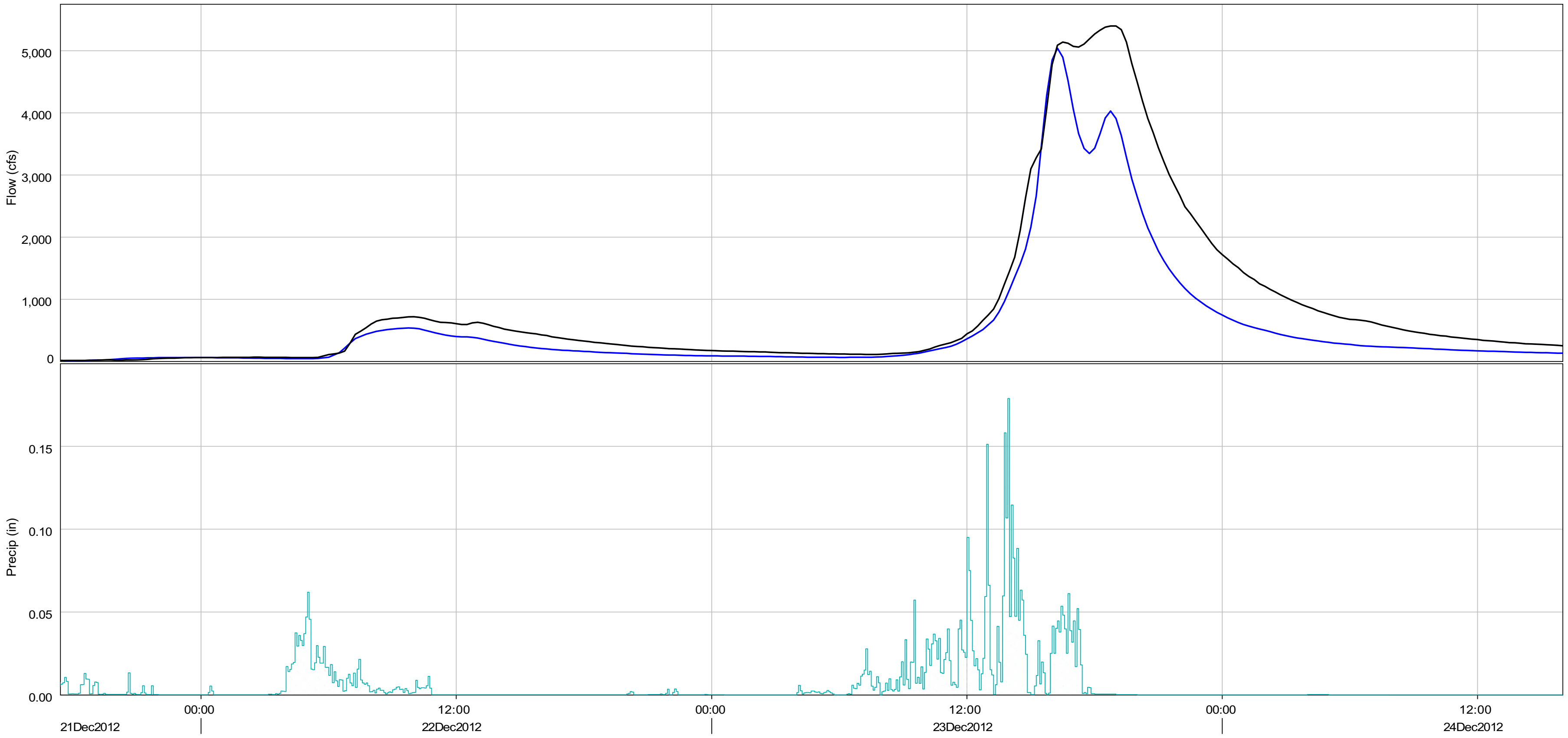


Figure 27: USGS – December 2012

NOTE: *Bear Creek and Los Trancos observed flow data were used as inputs in determining flow at USGS.*

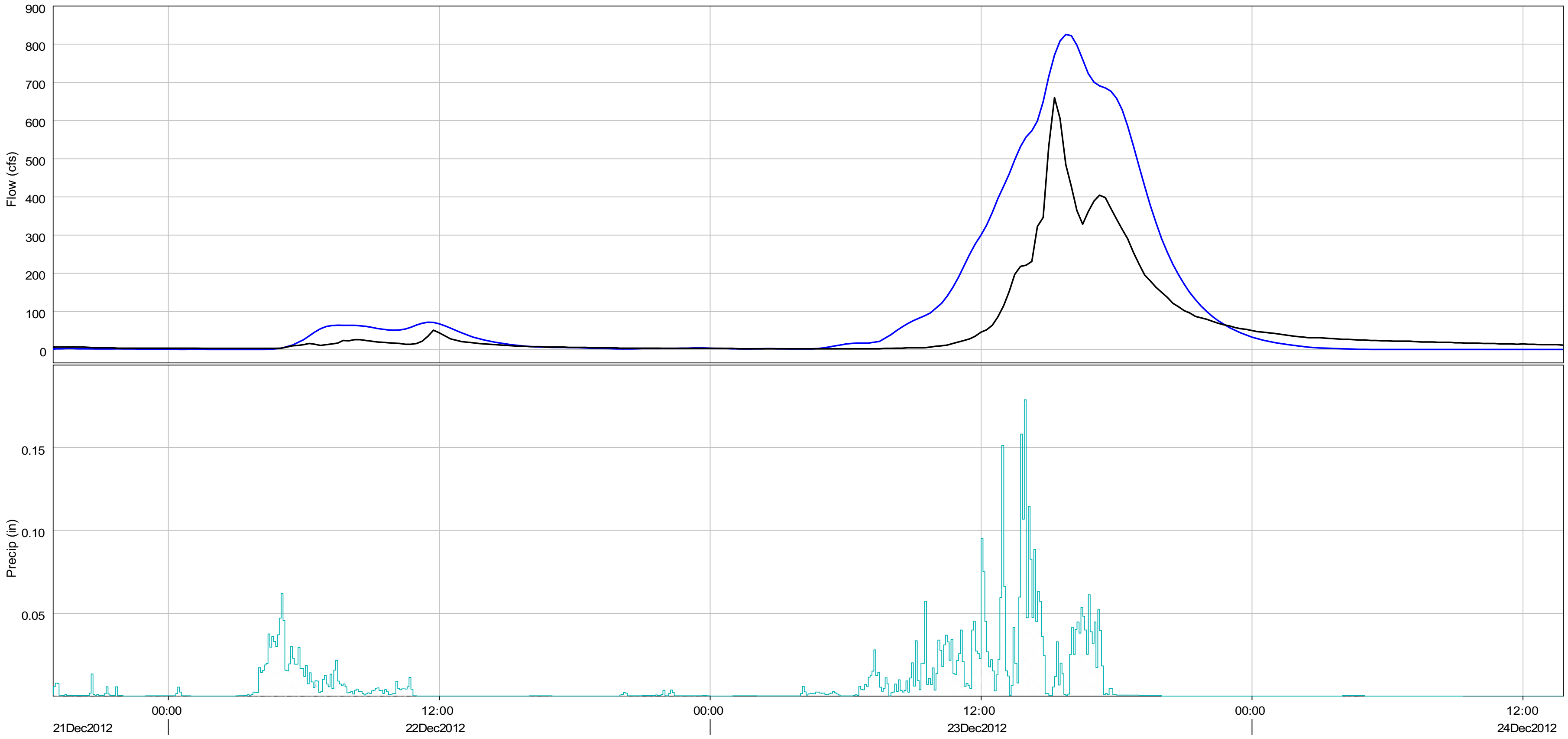


Figure 28: Los Trancos – December 2012

▨ Rainfall
— Model Output
— Observed Data

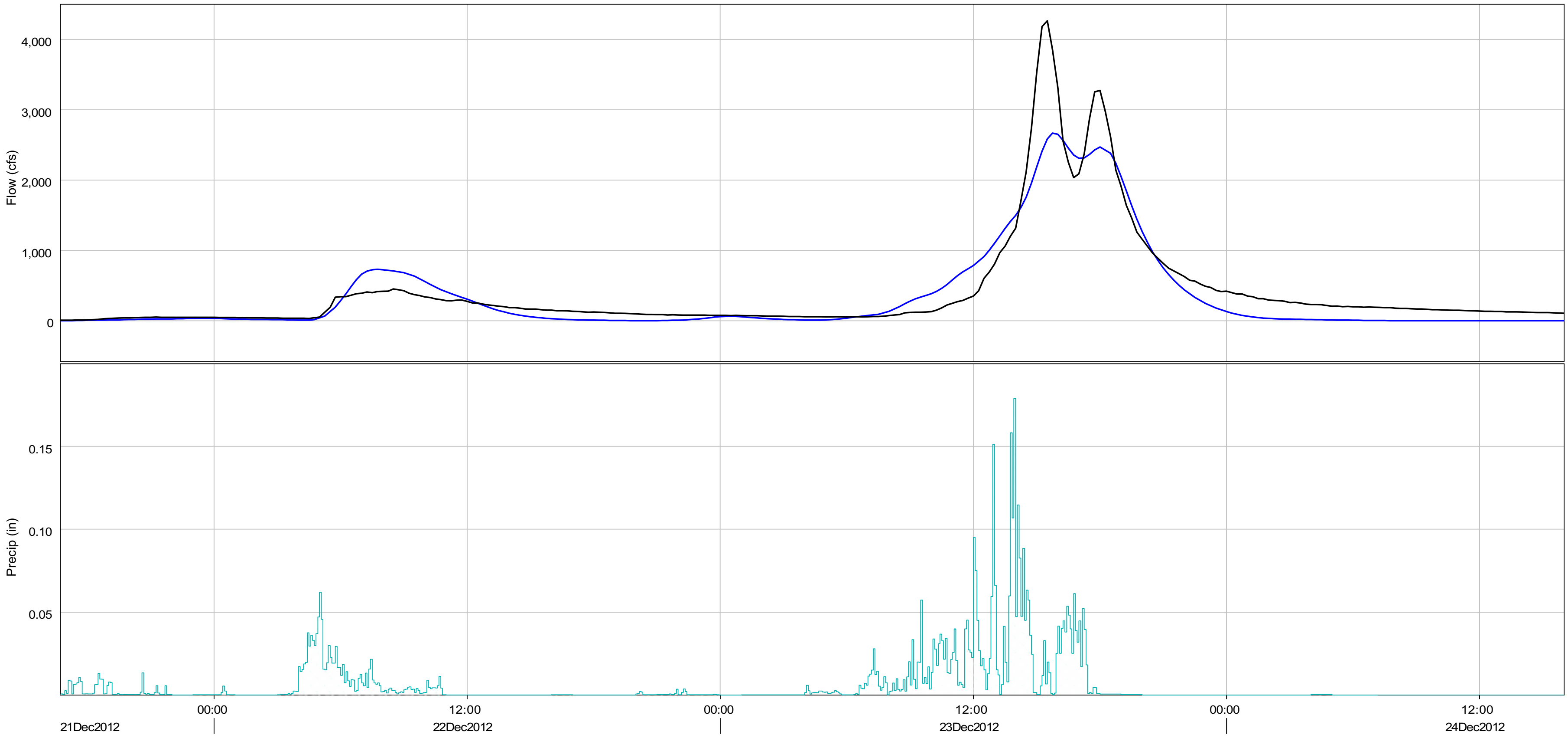


Figure 29: Bear – December 2012

NOTE: *Suspected rainfall data errors.*

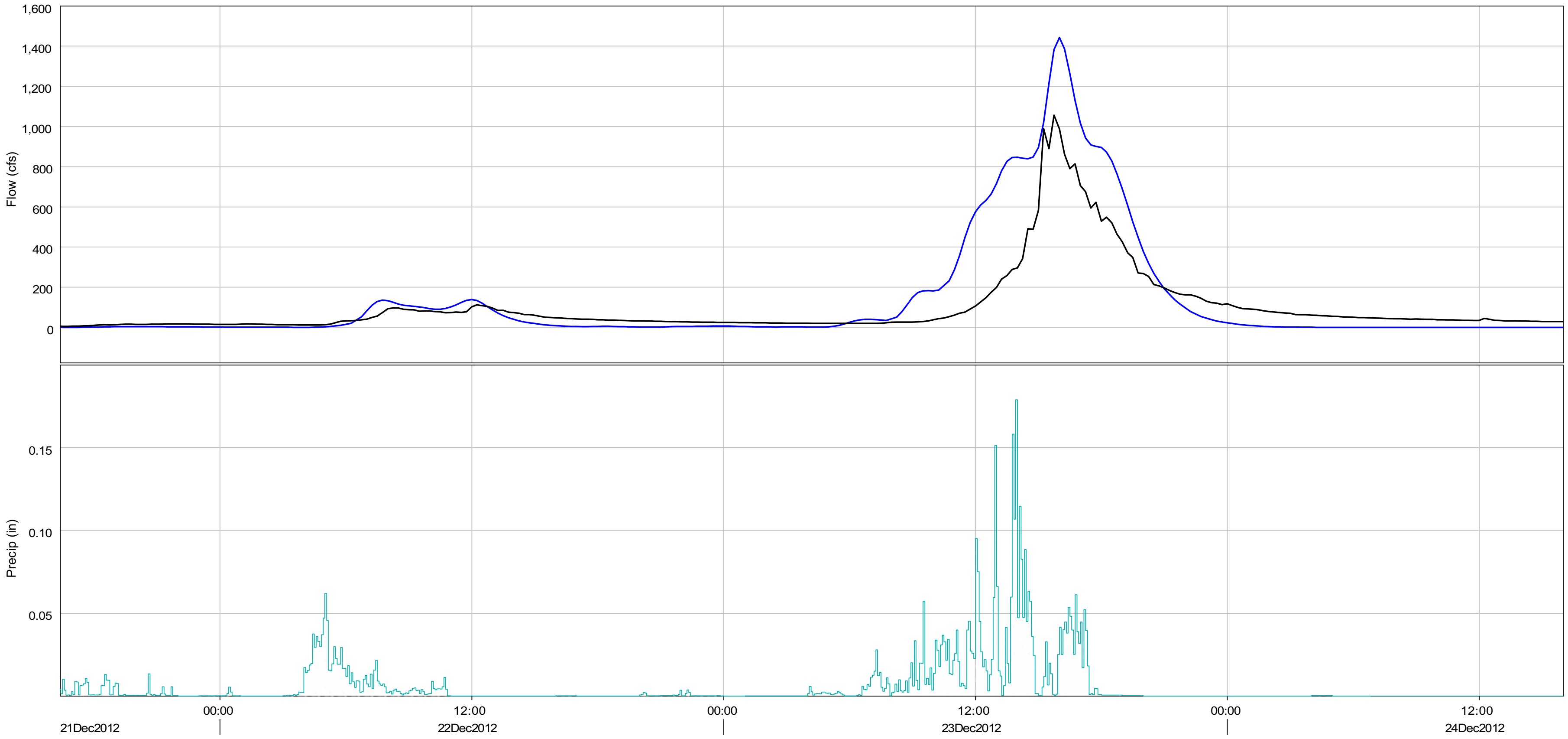


Figure 30: Corte Madera – December 2012

NOTE: *Stream gage located upstream of model catch point. Observed flow should be slightly lower than the model results.*

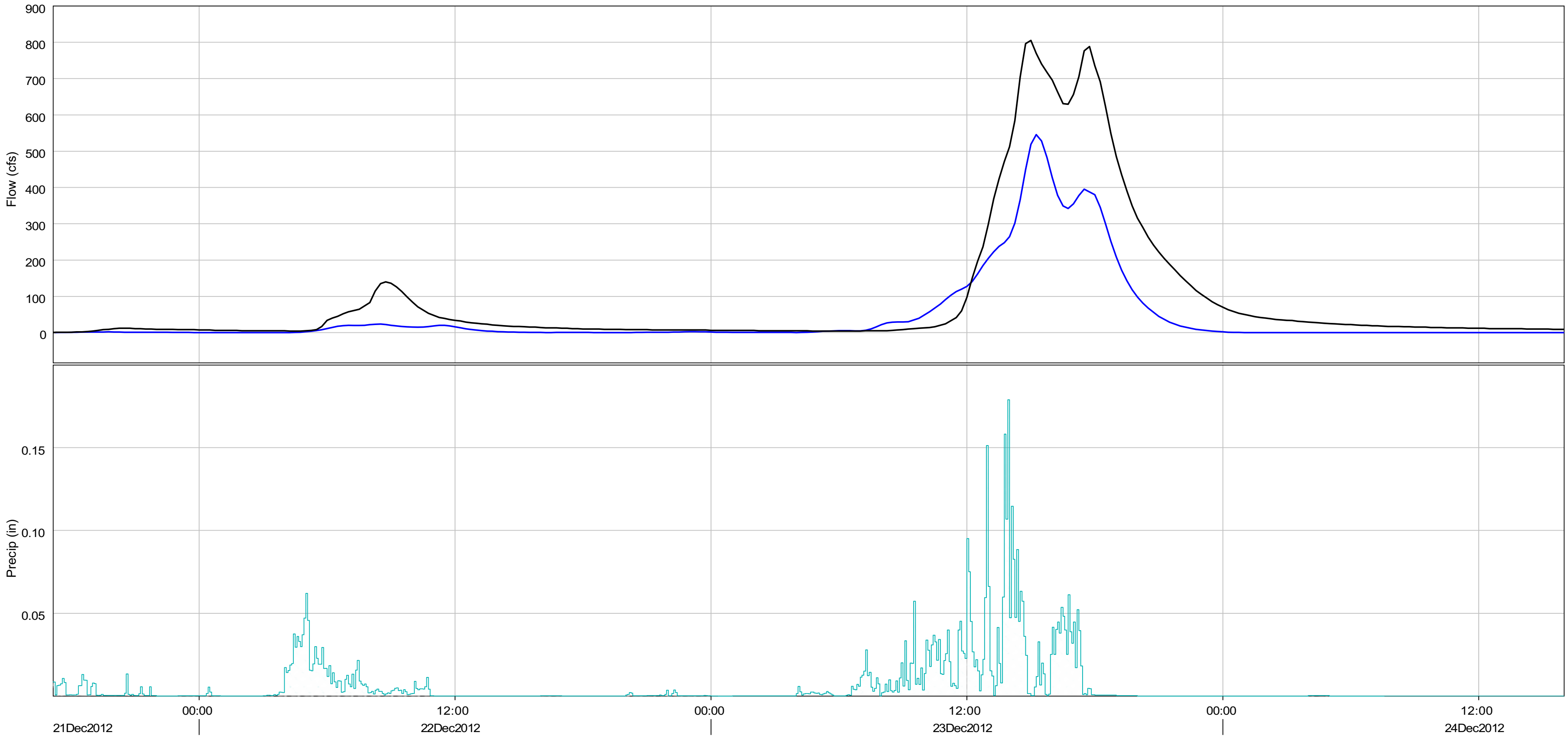


Figure 31: Dennis Martin / Sausal – December 2012

NOTE: *Suspected rainfall data errors.*

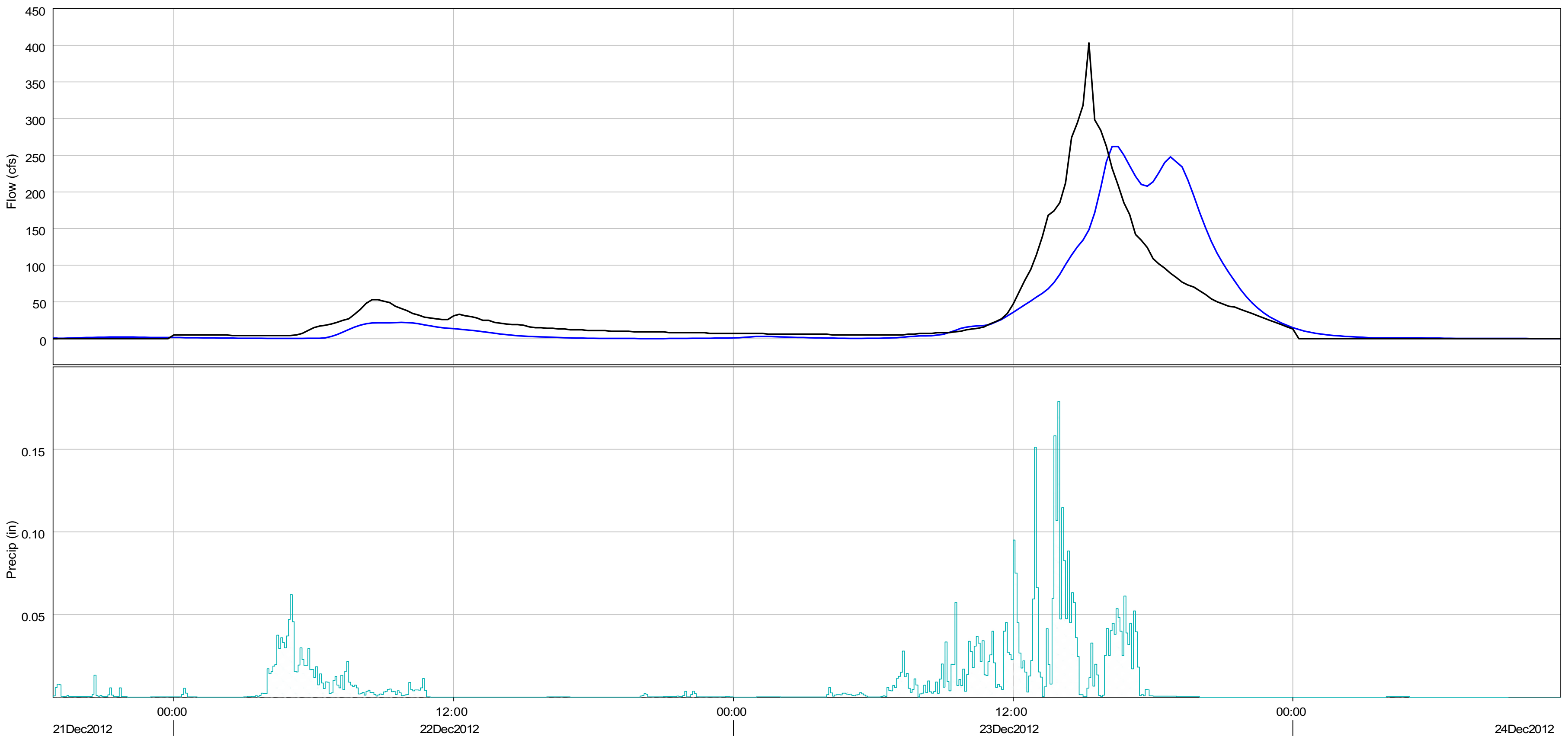


Figure 32: Alambique – December 2012

NOTE: *Culvert near gage clogged during storm. Observed flow data quality is poor at best, and determined from visual inspection. Rainfall data is also suspect.*

▤ Rainfall
— Model Output
— Observed Data

5. DESIGN STORM

5.1. PATTERN

Traditionally, the District has used a center-loaded 24-hour storm pattern based on rainfall statistics. This storm pattern is shown in Figure 32. However, a 72-hour storm pattern will also be used to account for the wetting behavior of Searsville Lake.

The storm of record for the entire county was in December 1955, and will be used as the basis for the 72-hr design storm. The storm pattern was modified by using precipitation frequency depths described in below. Depth durations of 1-hr, 2-hr, 3-hr, 6-hr, 12-hr, 24-hr, 48-hr and 72-hrs were used to ensure that within the 1955 pattern, each duration interval inside the design storm represented the statistically determined precipitation depths.

Rainfall depths are contingent upon mean annual precipitation (MAP) when using District rainfall equation, as explained in the next section. In lieu of creating a unique pattern for each sub-basin, the weighted-average MAP was determined for the entire watershed and used in the pattern modification for several reasons:

- The majority of the watershed is in the hills, and therefore does not have such a large variation in MAP compared with the valley.
- The differences in the patterns if each sub-basin was performed individually would be very slight, and from previous experience, not very sensitive.
- The design flow, regardless of rainfall depth and pattern, is calibrated to a gage FFA.

The aforementioned procedure was only done with 100-yr depths. The same pattern used for the 100-yr was adopted for the 10-yr design storm pattern for most of the same reasons listed above. The original 1955 storm pattern, as well as the modified storm pattern, is shown in Figure 33 and Figure 34.

5.2 RAINFALL DEPTH

NOAA-14 depths were not used to characterize the design storm. Previous hydrology studies using NOAA-14 rainfall depths yielded extremely high design flows, in many instances almost double the stream gage flood frequency analysis (FFA) flows. Similarly in this study, attempts to balance the flows by modifying model parameters became unreasonable. Therefore, The District's TDS regional equation is used to calculate the design rainfall depths. The District performed a statistical analysis on all forty rain gages within its jurisdiction to create the regression equation that can estimate precipitation for ungaged watersheds within this hydrometeorologic region.

Table 7 below compares 1% depths for both the 72-hr and 24-hr durations on all the San Francisquito sub-basins, and details the percent increase between the District and NOAA-14, which generally ranges from 20%-35%. Additionally, Table 8 compares the 1% depths between NOAA-14 and District statistical analysis for several durations at a District rain gauge that has been operating since 1966. Not only has the NOAA-14 depth increased for all durations, but the shorter duration depths now represent a higher percentage of the longer duration depths. The second point is important when producing the design storm pattern, and will increase the intensity design storm pattern at the peak, causing more runoff.

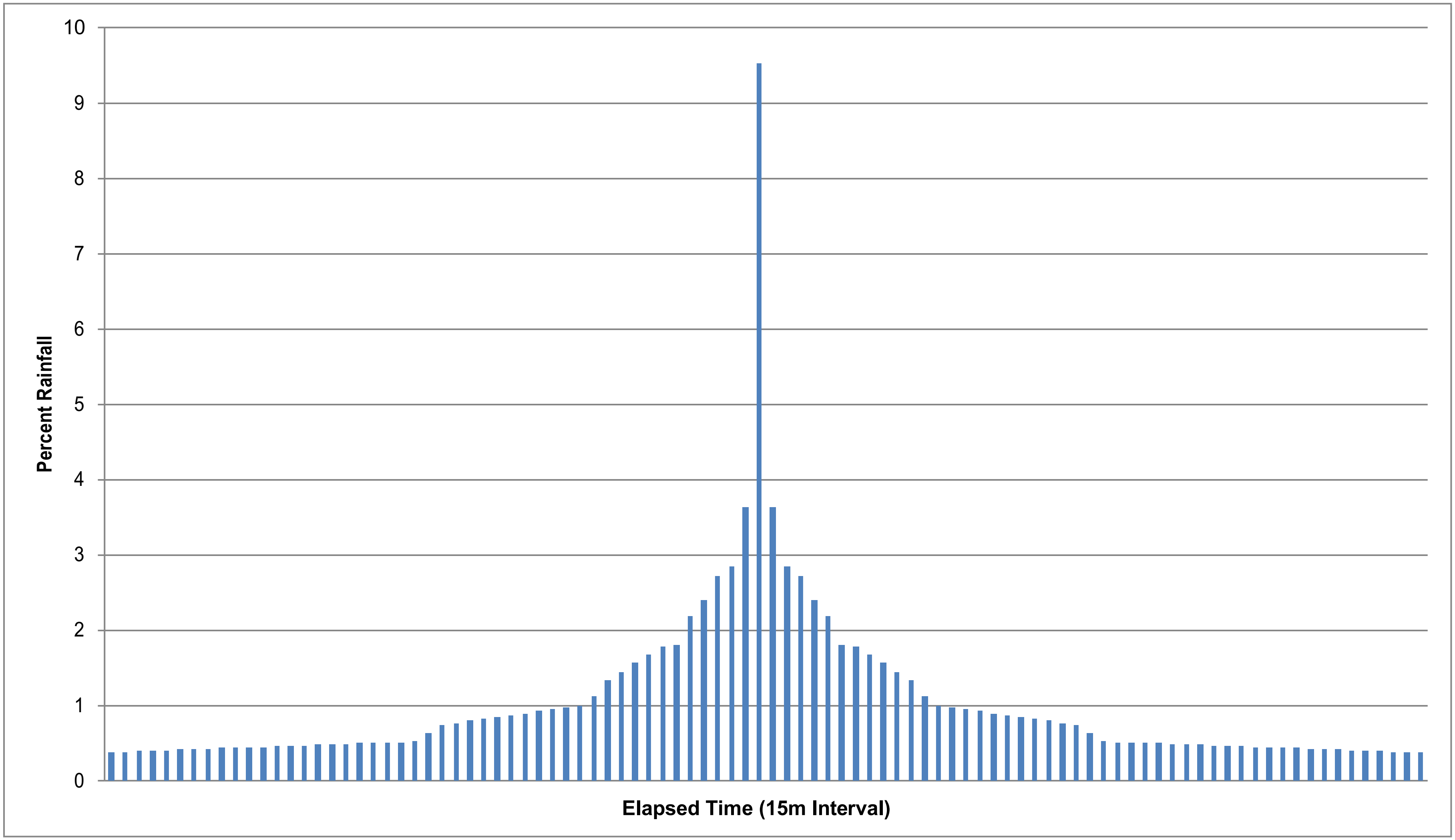


Figure 33: 24-hr Design Storm Pattern

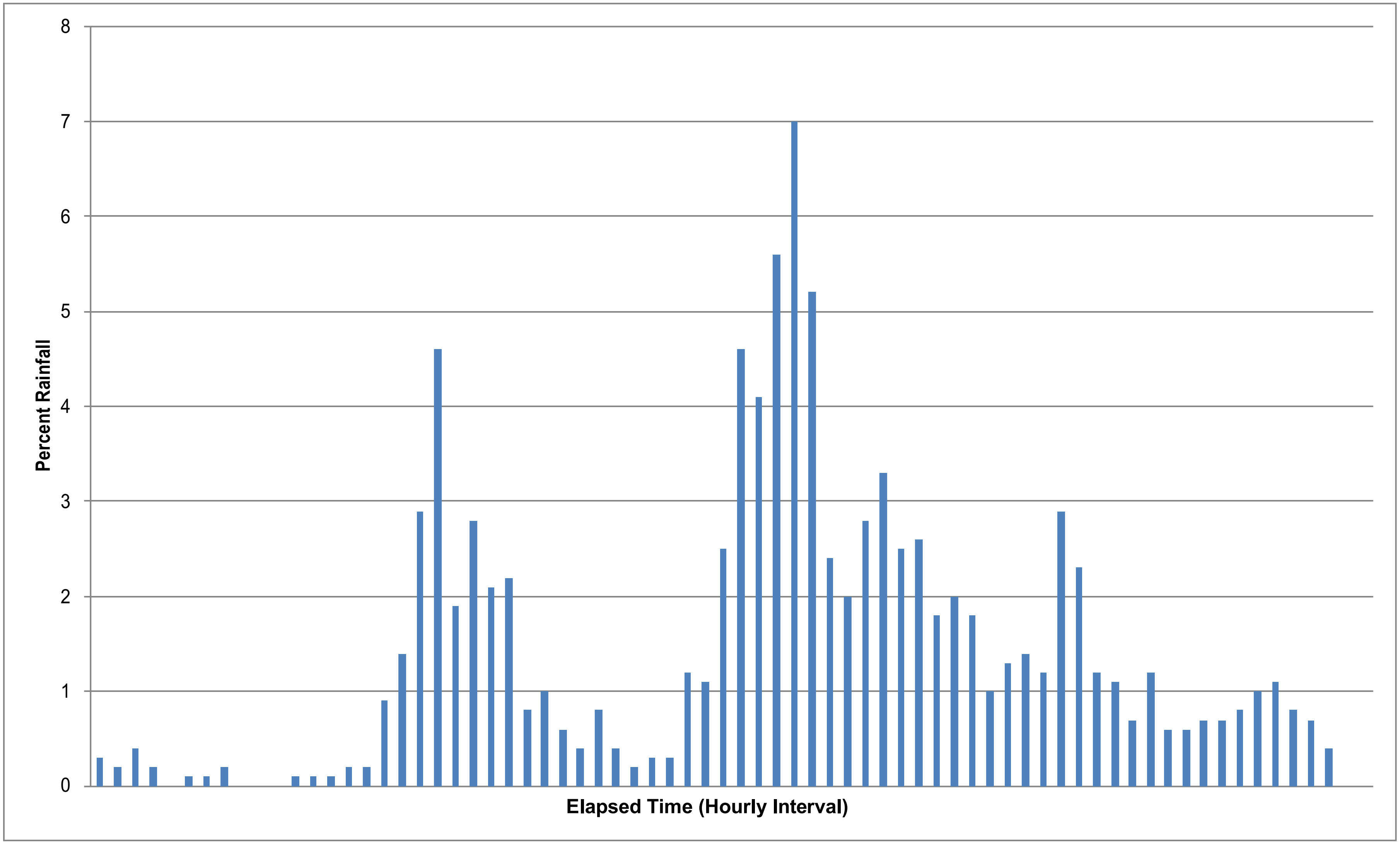


Figure 34: 1955 Storm Pattern

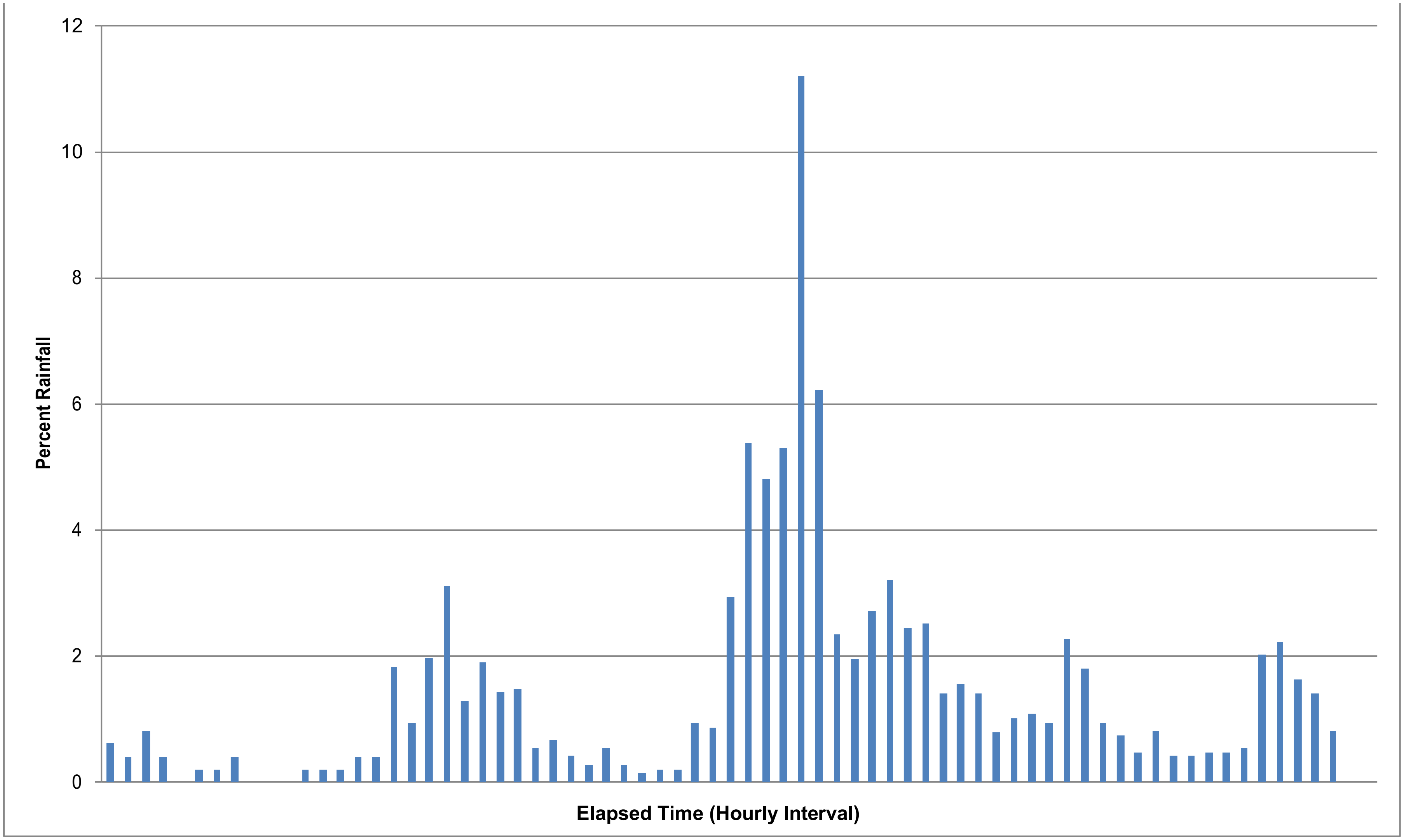


Figure 35: 72-hr Design Pattern

Table 7: Rainfall Depth Comparison

Basin ID	1% 72-hr			1% 24-hr		
	TDS	NOAA-14	% Increase	TDS	NOAA-14	% Increase
SFQ_AA14	8.34	11.4	36.7%	5.504	7.59	37.9%
SFQ_AA15	8.687	11.6	33.5%	5.727	7.58	32.4%
SFQ_A1	10.297	13.97	35.7%	6.76	9.16	35.5%
SFQ_A2	10.73	14.58	35.9%	7.038	9.46	34.4%
SFQ_BB11	9.363	12.27	31%	6.161	7.91	28.4%
SFQ_BB13	8.383	11.43	36.3%	5.532	7.43	34.3%
SFQ_B1	11.053	13.81	24.9%	7.245	8.76	20.9%
SFQ_C1	10.237	13.9	35.8%	6.722	8.89	32.3%
SFQ_C6	10.818	14.9	37.7%	7.095	9.51	34%
SFQ_D	10.677	14.56	36.4%	7.004	9.35	33.5%
SFQ_E	8.974	12.32	37.3%	5.911	7.97	34.8%
SFQ_F	7.676	10.2	32.9%	5.078	6.72	32.3%
SFQ_G1	10.049	12.05	19.9%	6.601	7.71	16.8%
SFQ_G2	9.163	11.1	21.1%	6.033	7.21	19.5%
SFQ_G3	7.649	9.92	29.7%	5.061	6.52	28.8%
SFQ_G4	8.197	9.91	20.9%	5.413	6.5	20.1%
SFQ_G5	7.347	9.14	24.4%	4.867	6.07	24.7%
SFQ_G6	6.784	8.69	28.1%	4.506	5.81	28.9%
SFQ_H	6.343	8.33	31.3%	4.223	5.62	33.1%
SFQ_I	6.226	8.12	30.4%	4.148	5.51	32.8%
SFQ_J1	5.961	7.84	31.5%	3.978	5.32	33.7%
SFQ_J2	5.624	7.52	33.7%	3.762	5.14	36.6%
SFQ_K	5.59	7.13	27.5%	3.74	4.96	32.6%
SFQ_L	5.565	6.87	23.5%	3.724	4.77	28.1%
SFQ_M	5.39	6.43	19.3%	3.612	4.52	25.1%
SFQ_N	5.151	6.06	17.6%	3.459	4.3	24.3%
SFQ_O	4.813	5.89	22.4%	3.242	4.2	29.5%

Table 8: Rainfall Depth and Percentage Comparison for Dahl Ranch Gauge

	1% Depth (and Percent)	
Duration	**SCVWD Gauge Stats**	**NOAA-14**
72-Hr	9.67	11.82
24-Hr	6.27	7.56
6-Hr	3.06	4.47
% of 72-hr	32%	38%
% of 24-hr	49%	59%
1-Hr	1.05	1.69
% of 72-hr	11%	14%
% of 24-hr	17%	22%

The total precipitation for a given storm duration and frequency can be determined from the following TDS equation published by the District[16].

$$P_{f,d} = A_{f,d} + B_{f,d} \times MAP$$

Where:

$P_{f,d}$ = Precipitation depth in inches for a given f, frequency (%) and d, duration (hours).
$A_{f,d}$ & $B_{f,d}$ = Regression constants and coefficients given in the table below
MAP = Mean annual precipitation, in inches, from SCVWD

Table 9: TDS Equation Constants

	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr	48-hr	72-hr
A (1%)	0.5074	0.5317	0.498	0.3228	0.2588	0.1102	0.3239	-0.0876
B (1%)	0.019	0.0389	0.0579	0.1082	0.1613	0.217	0.2751	0.3382
A (10%)	-	-	-	-	-	0.0028	-	-0.1569
B (10%)	-	-	-	-	-	0.1653	-	0.2552

Precipitation depth was calculated individually for each sub-basin in the hydrologic model using the TDS equation shown above due to the variation of MAP. TDS equations for the 10-year recurrence event were only used for the full 24-hr and 72-hr depths, as the other durations were not required since the pattern was already created using the 100-year event.

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[16] SCVWD 2013. Precipitation Gage Data and Depth-Duration-Frequency Analysis. Revised from Saah et al, 2004

5.3 DEPTH AREA REDUCTION FACTOR (DARF)

When accounting for spatial variation in rainfall depth over a large watershed, DARFs are commonly used. As the study area increases in size, there is a decrease in rainfall depth. To properly account for the spatial variation, the depth-area reduction table 13.3 in HMR 59[17] was used. HMR 59 analyzed the largest recorded storms in California to produce the DARFs. Values between the discrete points in the table were interpolated linearly. For San Francisquito, all depths were multiplied by 92.1%, which represents the DARF for a watershed area of 44.95 square miles.

5.4 SEARSVILLE LAKE

To properly model the hydraulic effects of Searsville Lake, a 2D model was used to route flows from the upper lake to the dam spillway. Output from the hydrologic model was used as input to the hydraulic 2D model, and the resulting output used as dam outflow for the hydrologic model.

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[17] NOAA. Hydrometeorological Report No. 59. Probable Maximum Precipitation for California, February 1999.

6. FLOOD FREQUENCY ANALYSIS (FFA)

6.1. DATA

The only stream gage with a significant historical record to perform a FFA is the USGS gage #11164500 at the Stanford golf course. This gage began measuring stream flow in 1932 and has since maintained a continuous length of record, except for a gap from 1942 to 1950. To date, there are 73 annual peak discharges over a period of 83 years.

Stream gage data was downloaded from the USGS National Water Information System [18] (NWIS). Analysis was performed using USGS PeakFQSA[19] software, which also includes an automatic low outlier test improved upon from the original Bulletin 17B, also known as 17C[20]. Gage analysis was performed using a weighted skew, with regional skews determined by USGS SIR 2010-5260[21], which followed the following equation:

$$\text{RRRRRRIIAAIIIII SSSSRRSS} = -0.62 + 1.3\,[\,1 - \quad \text{RR}\,(-\text{MMMMMMMMM BBMMBBBMM EEMMEEMMEEBBEEMM}/6500)^{2}\,]$$

Input parameters are listed below in Table 8. Station skew was calculated by the PeakFQSA program and varied depending on the outlier selection.

Table 10: USGS Gage Regional Skew & Mean Square Error

Location	Average Basin Elev	Skew	Mean Square Error
USGS Gage 11164500	953’	-0.60	0.14

6.2 RESULTS

Analysis was performed with two separate low-outlier test methods. The first was the Multiple Grubbs-Beck Test (MGBT) method, which is the default 17C method. The second MGBT method calculated a low-outlier threshold of approximately 1,600cfs. To test sensitivity, a manual low-outlier threshold of 139cfs was used based on visual examination of the data set. Both methods produced similar 100-year flows. 100-yr flows for both methods can be seen in Table 9. Graphs can be seen below in Figure 35 for the MGBT and Figure 36 for the manual threshold. Final FFA results for the MGBT method are in Table 9.

---

[18] http://nwis.waterdata.usgs.gov/nwis

[19] Tim Cohn, USGS. PeakFQSA Version 0.998. Flood Frequency Analysis with the Expected Moments Algorithm

[20] Recommended Revisions to Bulletin 17B. June 12, 2013. Subcommittee on Hydrology, Advisory Committee on Water Information. Hydrologic Frequency Analysis Work Group (HFAWG) Memorandum.

[21] Parrett, C., Veilleux, A., Stedinger, J.R., Barth, N.A., Knifong, D.L., and Ferris, J.C., 2011, Regional skew for California, and flood frequency for selected sites in the Sacramento–San Joaquin River Basin, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2010–5260, 94 p.

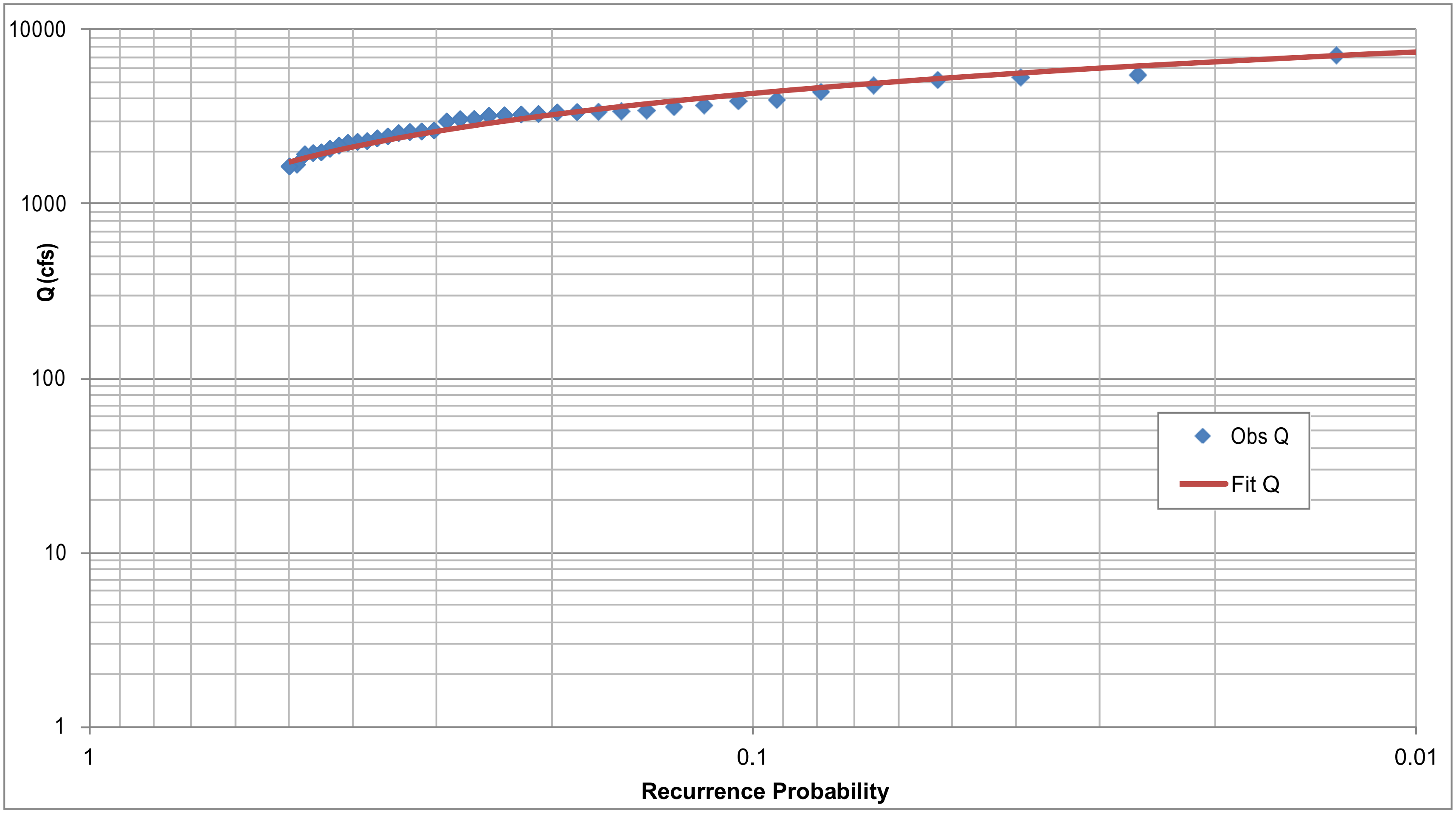

Figure 36: USGS Gage FFA Plot (MGBT)

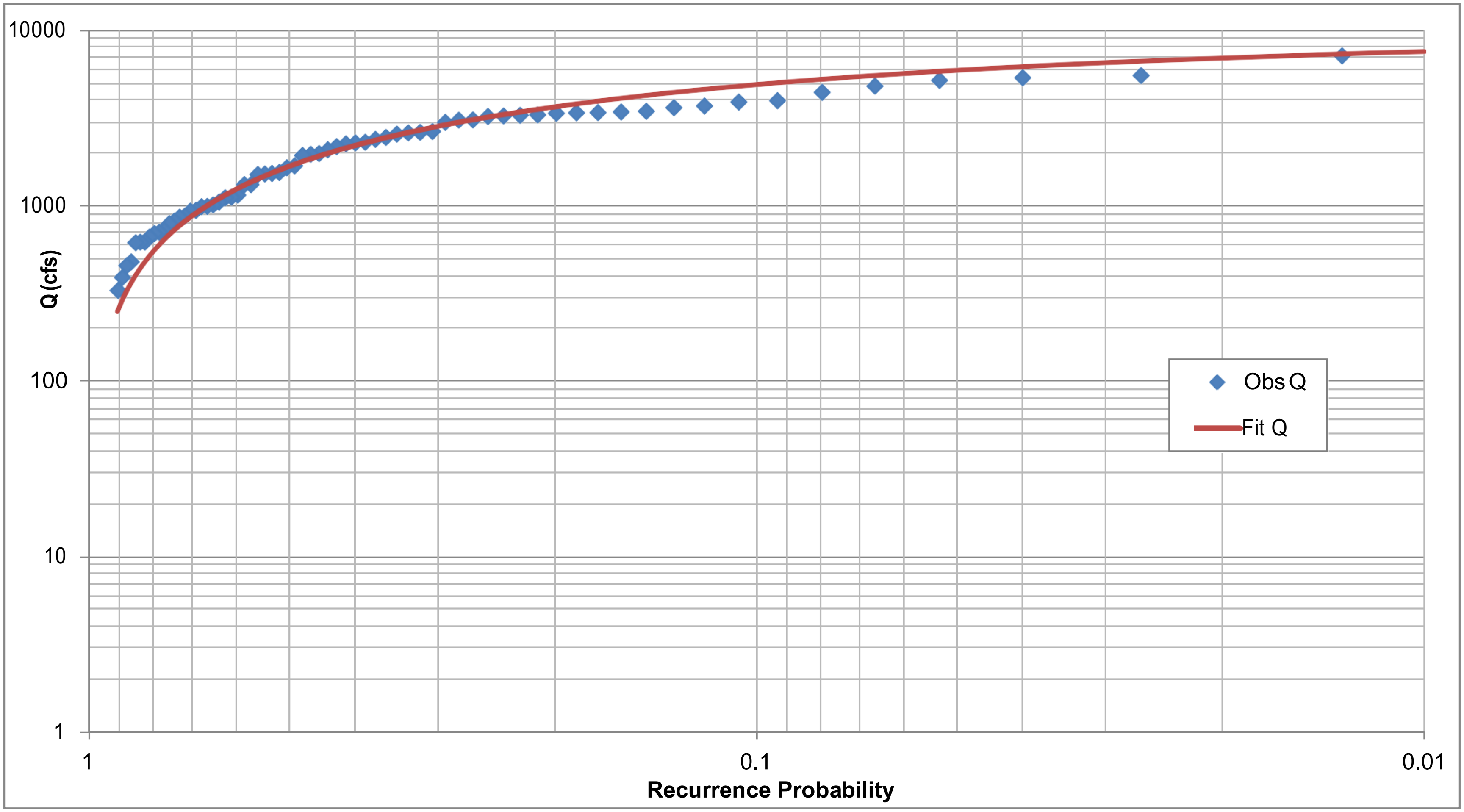

Figure 37: USGS Gage FFA Plot (139cfs Minimum Threshold)

Table 11: USGS Gage 11164500 FFA (MGBT)

Recurrence	Q Flow (cfs)
500yr	9,456cfs
200yr	8,382cfs
100yr	7,519cfs
50yr	6,612cfs
25yr	5,660cfs
10yr	4,330cfs
5yr	3,261cfs
2yr	1,734cfs

6.3 PREVIOUS INDEPENDENT ANALYSES

Two separate independent FFA studies were previously completed for the same gage. The first was a part of the Palo Alto Flood Basin Study by Shaaf and Wheeler in 2014[22]. The second was SIR 2010-5260, a study by the USGS in 2010 on all stream gages within the state of California that presents the most recent regional regression equations. Values vary slightly, due to additional data points, regional skew values, and low-outlier tests. However, all values are reasonably close. Table 10 below compares the different values.

Table 12: USGS Gage 100-yr FFA Comparisons

Study	Q100
Current Study (MGBT)	7,519cfs
Current Study (Manual Threshold)	7,547cfs
USGS SIR 2010-5260	7,690cfs
Shaaf & Wheeler PAFB	7,810cfs

6.4 SEARSVILLE DAM

The historical peak flows recorded by the USGS gage are influenced by the presence of Searsville Dam on the system. It is evident from recent large events that the lake and the dam provide a level of flood protection. However, given the dynamic change of the lake through sedimentation and the resulting topographic change upstream of the lake, it is not clear how the dam has affected the measured flows since the advent of the USGS gage.

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[22] Schaaf & Wheeler. Palo Alto Flood Basin Hydrology. July 2014. Prepared for SCVWD.

The prevailing thought is that as time passed, the lake gradually filled up with sediment, reducing the storage, and thereby increasing runoff downstream. Therefore, it is expected that the annual peak flows measured at the USGS gage would be higher in the past if Searsville Lake and dam, in its current state, was present. This might make our current FFA slightly low given the current conditions. However, this theory has not been verified. To offset this possible uncertainty, the design flow should be set conservatively higher than the results of the FFA.

7. DESIGN FLOWS

7.1. DESIGN MODEL PARAMETERS

Two design storm durations were used to ensure that the most conservative effect of Searsville Lake was captured. Although the design model will be calibrated to FFA value at the USGS gage, other catch points upstream of the gage do not have an index point and might be affected by storm duration.

For the 24-hr design storm pattern, an AMC of 1.65 was used. For the 72-hr design storm pattern, an AMC of 1.4 was used. Time of concentration values were based on a Q100 flows based on USGS regional regression values for each sub-basin, similar to the method used during model calibration. Storage coefficient ratios were left at 0.5 for all sub-basins.

A secondary HEC-HMS basin geometry was created as a “no Searsville lake” option. This model contained a few extra routing reaches to account for the distance in the HEC-RAS 2D model. This basin geometry was used to determine Searsville inflow values, as the Searsville tributaries in the original geometry was disconnected to allow the routing to be performed in the 2D model.

7.2 RESULTS

Model results for both the 24-hr and 72-hr design storms are below. The higher flow value between the two storms will be used as the final design storm.

Table 13: SFC 100-yr Design Model Output

Location	HEC-HMS ID	Q100 (24-hr AMC 1.65)	Q100 (72-hr AMC 1.4)	Final Design Flows
Searsville Inflow	SFQ_E_Lake	4,087	4,261	4,261
Searsville Outflow	Searsville Gage	2,938	3,022	3,022
Bear Creek U/S SFC	SFQ_AA15_Junction	2,863	2,883	2,883
Los Trancos U/S SFC	SFQ_G6_Junction	1,508	1,520	1,520
SFC U/S Los Trancos	SFQ_F_Junction	6,178	6,257	6,257
USGS	SFW_H_USGS_Junction	7,575	7,633	7,633
Pope Chaucer	SFQ_M_Junction	8,146	8,134	8,146
US-101	SFQ_N_Junction	8,404	8,352	8,404

Table 14: SFC 10-yr Design Model Output

Location	HEC-HMS ID	Q10 (24-hr AMC 1.65)	Q10 (72-hr AMC 1.4)	Final Design Flows
Searsville Inflow	SFQ_E_Lake	2,373	2,360	2,373
Searsville Outflow	Searsville Gage	1,690	1,690	1,690
Bear Creek U/S SFC	SFQ_AA15_Junction	1,768	1,784	1,784
Los Trancos U/S SFC	SFQ_G6_Junction	920	934	934
SFC U/S Los Trancos	SFQ_F_Junction	3,606	3,668	3,668
USGS	SFW_H_USGS_Junction	4,434	4,473	4,473
Pope Chaucer	SFQ_M_Junction	4,813	4,802	4,813
US-101	SFQ_N_Junction	4,976	4,943	4,976

7.3 FINAL FLOWS

Using the computed 10-yr and 100-yr design flows, interpolation and extrapolation was performed using Log-Pearson Type III methodology described in Bulletin 17B[23]. The general distribution fit is defined by the following equation:

$$LLAARR\ QQ = \bar{X} + KK \times SS$$

In this case, the flow variable Q is known for the 1% and 10% frequencies, as well as the constant factor K that is obtained from Appendix 3 of Bulletin 17B given a general skew coefficient G, which is determined to be -0.60. That leaves X-bar and S as two unknowns that can be solved.

Final design flows, along with associated K, S, and X-bar values can be seen in Table 13.

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[23] Guidelines for Determining Flood Flow Frequency– Bulletin #17B of the Hydrology Subcommittee. Interagency Advisory Committee on Water Data. Revised 1981. Editorial Corrections March 1982. USGS.

Table 15: Final Design Flows

	Recurrence Interval								Calculated Values	
Location	**2.33-Yr**	**5-Yr**	**10-Yr**	**25-Yr**	**50-Yr**	**100-Yr**	**200-Yr**	**500-Yr**	**S**	**X-bar**
Searsville Inflow	1,080	1,780	2,380	3,140	3,700	4,270	4,760	5,420	0.36963	2.93164
Searsville Outflow	780	1,270	1,690	2,230	2,630	3,030	3,370	3,840	0.36701	2.78738
Bear Creek U/S SFC	940	1,410	1,790	2,250	2,570	2,890	3,160	3,510	0.30309	2.88760
Los Trancos U/S SFC	490	740	940	1,180	1,350	1,520	1,670	1,860	0.30752	2.60124
SFC U/S Los Trancos	1,790	2,820	3,670	4,740	5,500	6,260	6,920	7,790	0.33724	3.15965
USGS	2,180	3,430	4,480	5,780	6,710	7,640	8,440	9,500	0.33747	3.24554
Pope Chaucer	2,370	3,710	4,820	6,190	7,170	8,150	8,990	10,100	0.33228	3.28358
US-101	2,460	3,840	4,980	6,390	7,400	8,410	9,270	10,410	0.33094	3.29966
K-Value	0.27047	0.85718	1.20028	1.5283	1.72033	1.888029	2.01644	2.16884		

8. FUTURE CONDITIONS

8.1. WATERSHED URBANIZATION

In the hills, much of the area is open space preserve and protected from development. In the upper valley, by Searsville Lake, there is very light urbanization on mostly rural tracts of land. In the lower valley, Palo Alto and Menlo Park are essentially fully built out.

Given this information, it is not likely that imperviousness, a measure of urbanization, will change considerably in the next fifty or so years.

8.2. SEARSVILLE DAM

8.2.1. EXISTING CONDITION

Currently the dam provides very little storage in the reservoir proper due to sedimentation. However, there is a definite observed attenuation[24] from historical storms and modeling observations seem to indicate two main factors causing attenuation upstream of the lake:

- For the tributaries feeding into Searsville Lake, the channel capacity is very limited. There is significant usage of floodplains by these tributaries once the low flow channel is exceeded.
- Two constrictions from roadway crossings exist that divide the area upstream of the reservoir. The first is Portola Road crossing Alambique Creek. The second is the Stanford Causeway that spurs off Lakeshore Drive, which is a part of the Stanford Jasper Ridge preserve.

The combination of floodplain usage and roadway constrictions creates artificial detention ponds upstream of Searsville Lake, causing the observed attenuation. Map details can be seen in Figure 2.

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[24] Xu, Jack. SCVWD. Technical Memorandum - Effect of Searsville Lake on Large Storm Events. March 25, 2015.

8.2.2. FUTURE CONDITION

Stanford’s Searsville Alternatives Study Committee (SASC) was formed in 2011 by the Stanford University Provost to develop a recommended course of action to address the future of Searsville Dam and Reservoir. SASC is comprised of twelve Stanford University administrators, prominent faculty, including specialists in conservation, land use, environmental sustainability, and water conservation. The results of their findings are published in the Searsville Alternatives Study[25].

SASC has identified not exacerbating flood risk as a primary goal of future Searsville operations. Future Searsville operation is uncertain as Stanford is currently in litigation. However, the Searsville Alternatives Study put forth by SASC recommends two options:

- Let the dam silt in and build a fish ladder passage.
- Create an orifice at the dam base and excavate the sediment inside the lake.

To reflect a the possibility of a silted in dam, a hypothetical condition of a filled in dam was analyzed, where the 1% design storm for both the 24-hr and 72-hr was run with a starting water surface at the invert of the lowest gate in the 2D model to simulate a completely full dam. Results were compared to the existing run and there was no difference in peak flow or timing.

As for the second orifice condition, the details of the orifice size and invert are not known at this point. It is known that the opening needs to facilitate fish passage, but also provide attenuation during high flows.

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[25] Searsville Alternatives Study, Steering Committee Recommendations. Stanford University. April 2015.

APPENDIX A

Santa Clara Valley Water District

TECHNICAL MEMORANDUM

PROJECT: San Francisquito Creek – Searsville Lake **DATE**: March 25, 2015

SUBJECT: Effect of Searsville Lake on Large Storm Events

PREPARED: Jack Xu, PE

1. PURPOSE

The purpose of this report is to quantify the causes of attenuation for Searsville Lake and the effects on San Francisquito Creek flows during significant storm events.

2. BACKGROUND

Searsville Dam is owned and operated by Stanford University, and was constructed in 1892, creating Searsville Lake. The watershed upstream of the dam is approximately 14.5 square miles, which accounts for about a third of the total watershed of San Francisquito Creek. A general map can be seen in Figure 1.

The lake experiences severe sedimentation from upstream sources. According to the Searsville Lake Impact Study[1], varying sedimentation rates averaging about 9 acre-feet per year have occurred over the past 100-plus years. This has significantly decreased the amount of storage that the lake can hold. Currently, from field visits and conversations with Stanford and Balance Hydrologics, the dam will spill through manual gates even during a very minor storm event, and experience uncontrolled overtopping soon thereafter.

However, observations from recent large flood events show that heavy runoff routed through Searsville Lake provided a flood benefit for San Francisquito Creek and communities downstream, either by delaying the timing of the peak flow, or by attenuating the peak flow and releasing the volume over a longer period of time. A case study was performed for the 2012 event to detail the benefits of a lake and no lake scenario in this analysis. Benefits vary widely, and subsequent discussion will focus on determining the behavior of the lake.

3. METHODOLOGY

Analysis focused on using measured data where available. Effort was made to interpret the data to evaluate probable explanations for the attenuation. To augment the dataset where there was missing information, a two-dimensional hydraulic model was constructed, since field visits and general knowledge of the area surrounding the Lake revealed that the attenuation effects were too complicated for a simple model. Using multiple historic events, the 2D model was calibrated and verified. Most of the modeling work and calibration was done for the 2015 San Francisquito Hydrology Study[2]. This study is currently in a draft-review phase, but the calibrated 2D model, along with input data, and historical storms, were utilized for this study used to help analyze the effects of Searsville Lake.

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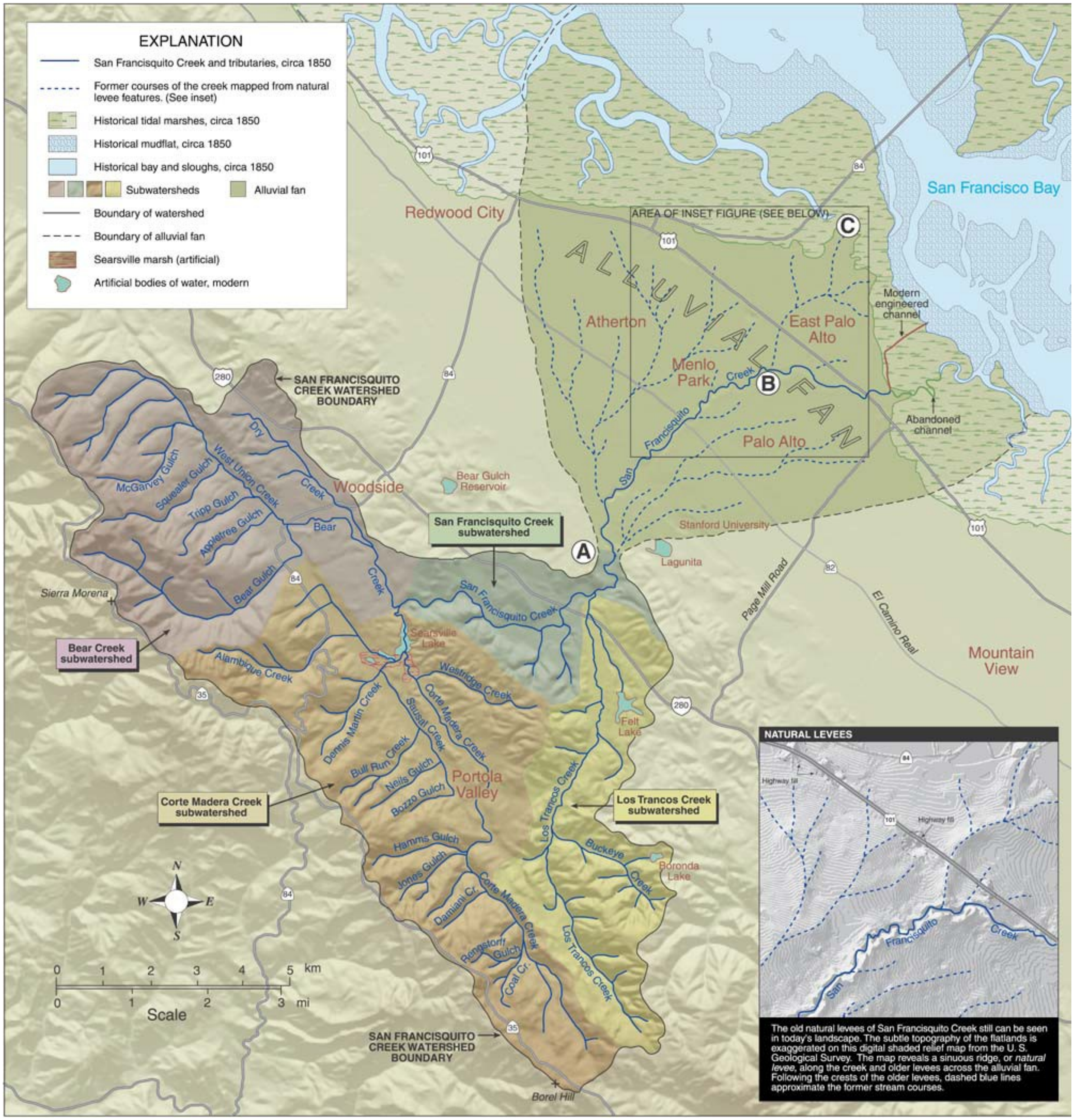
[1] NHC. Balance Hydrologics. HT Harvey & Associates. Jones & Stokes. Kondolf, Matt. Smith, Jerry. Searsville Lake Sediment Impact Study. Stanford University, Facilities Operations. March 2002.

[2] SCVWD. Xu, Jack. San Francisquito Hydrology Study. 2015.



The old natural levees of San Francisquito Creek still can be seen in today's landscape. The subtle topography of the flatlands is exaggerated on this digital shaded relief map from the U. S. Geological Survey. The map reveals a sinuous ridge, or *natural levee*, along the creek and older levees across the alluvial fan. Following the crests of the older levees, dashed blue lines approximate the former stream courses.

Figure 1: San Francisquito Watershed Map

4. HYDROLOGIC DATASET

To analyze the effects of the lake on downstream flows, large historical flow events that had inflow and outflow measurements for Searsville Lake were needed. Upon solicitation, Balance Hydrologics furnished pertinent stream flow data for the events that will be analyzed in this report. However, the data provided was not exhaustive for the events analyzed and missing data was estimated. Several methods were used to fill in the data gaps:

- For the 2011 and 2010 events, only one upstream tributary (Corte Madera Creek) was gaged. These events also had reliable gage adjusted radar rainfall data, and were used in the historical calibrations in the hydrologic model. Therefore, outputs from the HEC-HMS hydrologic model prepared by the 2015 San Francisquito Hydrology Study were used as tributary inflow inputs for the HEC-RAS models.

- For the 2005 event, Corte Madera Gage was the only gaged location as well. However, rainfall data was not reliable. Therefore, the remainders of the tributary inflows were determined by scaling the Corte Madera Creek hydrograph based on drainage area.

- The 2012 event had two gaged tributaries upstream of the Lake. Additionally, a third tributary had visual observations for estimated flow. For the remaining tributaries, flow was determined by scaling the hydrographs from the average of the two gaged tributaries, in the same manner as the 2005 event. However, for the tributary with visual observations, the hydrograph was modified so that the observed flow values properly fit within the rising and receding values of the scaled hydrograph.

- In 1998 and 2000, there were no gaged tributaries upstream of the Lake. Therefore, gage adjusted radar rainfall data was used in the HEC-HMS hydrologic model and the appropriate outflows were used as inputs into the 2D model.

- In 2000, there was no outflow data for Searsville Dam. The 2D model was used to determine the outflow during that time.

Four separate hydrographs were developed based on the different tributary sub-catchments to quantify the 2D model inflow. This was necessary to properly model the attenuation created by different topographic features in the 2D model, such as Portola Road and Family Farm Road.

- Alambique Creek

- Corte Madera Creek

- Dennis Martin & Sausal Creeks

- Additional sub-basin tributary to the Searsville Lake not included in the previous three

5. HYDRAULIC 2D MODEL

HEC-RAS 5.0.0 BETA, released October 2014, will be used to perform the 2D analysis. RAS 5.0 was chosen as the software of choice due to the simplicity of its 2D application, as well as its industry standard use. The October 2014 release is the final BETA release before the final release, and runs very stable with few issues.

A 2D computation mesh was created by using a *.LAS dataset from the 2006 LiDAR survey that generated a digital terrain model with 10' x 10' squares. This dataset was cleaned to remove errant reflectivity data from foliage and buildings by the survey vendor. Relevant hydraulic structures were inputted with data from Balance Hydrology's 1D HEC-RAS model[3] of Searsville that was sent to the District for review in 2014. The outfall of the entire model was modeled as a 2D Boundary Condition Line, which uses a rating curve generated from Balance Hydrology's model. This curve was double checked with recorded stage and flow data from historical events, which was also provided by Balance.

The 2D Boundary Condition Line spans six grid elements, and during simulation, five of those grid elements are wetted. Due to program limitations in the beta, water surface elevations can only be determined on a grid-by-grid basis while in the 2D domain. Conversation with Gary Brunner, lead developer at HEC, revealed that the computational scheme allows for different water surface elevations within each grid at the boundary condition line. Each grid independently uses the rating curve based on its connection at the boundary condition line. Therefore, there are slight variations in the water surface elevations, depending on grid characteristics. The five wetted grids will be average to determine a single water surface elevation, which will be used to determine flow from the rating curve.

Computational point spacing for the mesh was set at 100' x 100' and 50' x 50', depending on the detail required. A sensitivity analysis that ran the same model at a 10' x 10' mesh showed negligible output difference. The diffusive wave computational method was selected over the full dynamic solution due to the lack of potential energy losses through obstructions. A sensitivity analysis using different methods also yielded negligible difference.

To properly characterize the lake, several historical calibrations were run to determine if the model is accurate. When available, stream gage data was used as input into the model. HEC-RAS inputs from other tributaries that were not gaged were estimated, similar to the methods detailed in Section 4. A final manning's roughness coefficient of 0.1 worked well for all the historical storms. Results from the calibration and verification process are further detailed in the San Francisquito Hydrology Study.

The 2D model was the same model used in the 2015 San Francisquito Hydrology Study to characterize the effects of the Lake within the hydrologic HEC-HMS model.

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[3] Sears_US_JPA_052114.prj. Balance Hydrology is Stanford University's consultant.

6. BASELINE OBSERVATIONS

A total of six historical storms were looked at by using the data as described in Section 4. Each storm event was characterized as either being a storm where Searsville Lake had significant attenuation effects (blue), or a storm where the Lake had nuanced attenuation effects (orange). The peak lag time between inflow and outflow, and the overall peak flow reduction, were parameters used to quantify attenuation. Table 1 below documents each storm and the associated attenuation.

Table 1: Historical Lake Attenuation

Historical Event	Peak Inflow (cfs)	Peak Outflow (cfs)	Peak Lag Time (hrs)	Reduced Flow (cfs)	Flow Reduction (%)
2012	2481	1553	3.25	928	37.4%
2011	794	619	3.5	175	22.0%
2010	1429	982	2	447	31.3%
2005	2478	1258	2	1,220	49.2%
2000	1486	1068	1.5	418	28.1%
1998	3023	2588	0.5	435	14.4%

From the table above, there are two events that have parameters that do not necessarily fit the mold. For 2011, there is such a small peak flow reduction, but a large lag time. For 2000, the numbers are very close to the 2010 event. However, it is suspected that the inflow and outflow values for 2000 are less reliable, since there was no gage data for the entire watershed and since all the data was being handled by models.

It is also noted that the attenuation effects of the storm do not seem to follow a trend based on the peak inflow. The 2012 and 2005 events experienced significant attenuations, while the 1998 event experienced very little.

7. ANTECEDENT CONDITIONS

It is well known that the antecedent condition of the watershed can profoundly affect runoff. To analyze this, two datasets were looked at to determine the saturation of the watershed prior to the peak rainfall events for the six storms; antecedent rainfall and baseflow conditions prior to the largest inflow.

For antecedent rainfall, gage adjusted radar rainfall data was looked at one day prior to the peak rainfall intensity for five out of the six events. The 2005 data was extremely suspect and not used. A one day look-back period was used since the gage adjusted radar rainfall data began 24 hours prior to the peak rainfall intensity.

A longer look-back period was not pursued, due to the distance of the nearest rain gage which would provide the data. The nearest rain gage station that was operational during this time frame was at Dahl Ranch. This is a District gage that is on the edge of the entire San Francisquito watershed, just to the east of the Los Trancos Creek tributary area. Due to the observed temporal variation of storms in this area, it was decided not to pursue the use of that gage.

Figure 2 shows a scatter plot of the rainfall percentage that falls during the 24-hr look-back period for the five storm events. Hour zero is the earliest point in time, while hour 23 is the time of highest rainfall intensity. From the plot, the storms in 1998 and 2000 exhibit a higher percentage of rainfall during the earlier hours, while the storms in 2010, 2011, and 2012 have the majority of the rainfall occurring during the immediate hours before the peak rainfall intensity.

Cross referencing the observations from Figure 2 with Table 1, there is a slight trend showing that more attenuation is provided when there is a smaller percentage of antecedent 24-hr rainfall. The 2011 event is an outlier, when looking at peak flow attenuation, but has very large lag time attenuation.

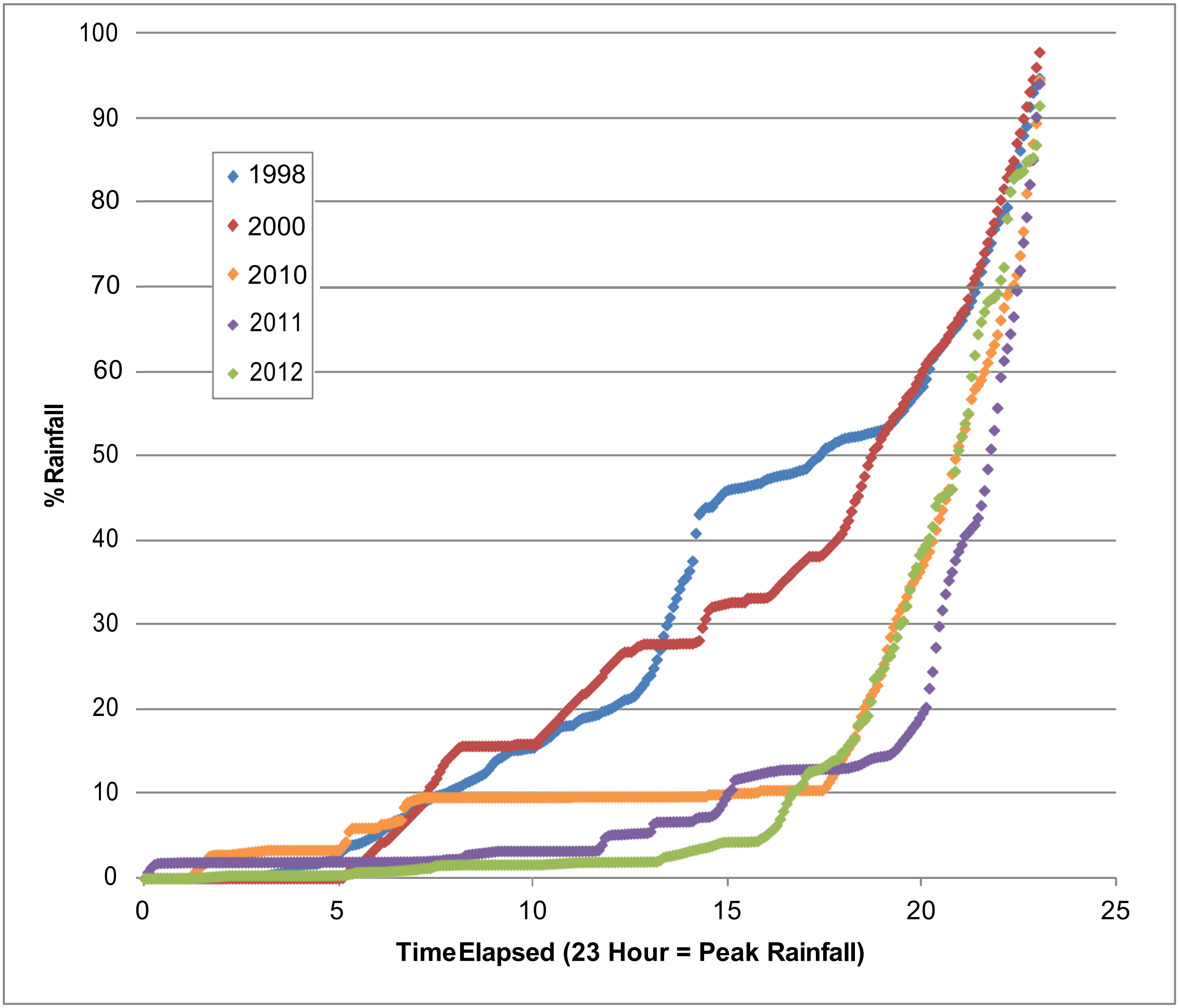

Figure 2: 24-Hr Antecedent Rainfall

The second dataset analyzed was observed baseflow prior to the largest inflow. To determine baseflow, recorded Searsville Lake outflow data was used. The prevailing baseflow was determined to be the lowest flow before the peak hydrograph recorded at Searsville Lake, marked as point B on Figure 3, which was taken from Chow et al[4]. Table 2 summarizes the recorded low flows for five of the six events, as Searsville Lake was not being recorded in 2000. The results suggest that a lower antecedent baseflow produces a larger attenuation. The resulting events are then characterized as having significant attenuation (blue) or nuanced attenuation (orange) based on the antecedent patterns. A graphical representation of the effects of prior low flow to flow reduction is in Figure 4.

Table 2: Prevailing Baseflow

Historical Event	Peak Inflow (cfs)	Peak Outflow (cfs)	Peak Lag Time (hrs)	Flow Reduction (%)	Prior Low Flow (cfs)
2012	2481	1553	3.25	37.4%	30
2011	794	619	3.5	22.0%	65
2010	1429	982	2	31.3%	35
2005	2478	1258	2	49.2%	15
2000	1486	1068	1.5	28.1%	N/A
1998	3023	2588	0.5	14.4%	70

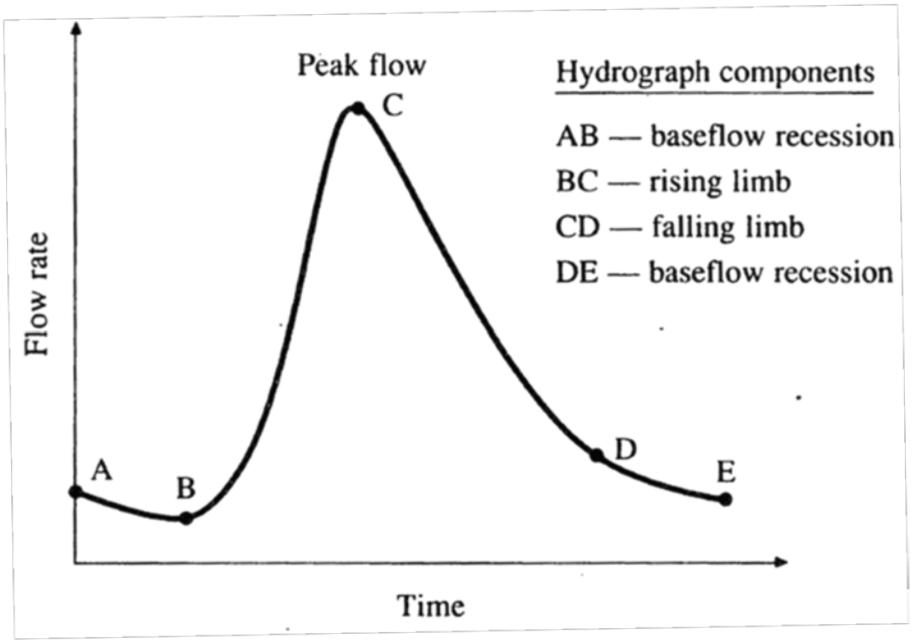

Figure 3: Baseflow Hydrograph Reference

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[4] Chow, Ven Te. Maidment, David R. Mays, Larry W. Applied Hydrology. Published 1988. McGraw-Hill.

8. INFLOW VOLUME

Although a peak flow may help characterize a storm's intensity, an analysis was done to determine the relative inflow volume into the Lake during the rising limb of the hydrograph. The rising limb was used to see the utilization of storage within the Lake in attenuating the peak. Using the inflow data detailed in Section 4, inflow volume was determined for the six hours preceding the peak inflow. Six hours was observed to generally be representative of the rising limb of the hydrograph for these storm events.

The 6-hour total volume during the rising limb was then divided by the observed peak inflow. This ratio helps normalize the volume to the size of the storm, and characterizes the general shape of the inflow hydrograph. A higher ratio of volume/peak would infer a wider hydrograph, while the reverse would be true for a lower ratio. Table 3 summarizes the results from these analyses. In general, the higher volume/peak ratios have less attenuation, while the lower volume/peak ratios exhibit more attenuation. Resulting events are characterized as having significant attenuation (blue) or nuanced attenuation (orange) based the volume/peak ratio. Figure 4 summarizes the effect of 6-hr inflow volume and prior inflow volume to flow reduction.

Table 3: Inflow Volume

Historical Event	Peak Inflow (cfs)	Flow Reduction (%)	6-Hr Inflow Volume (AC-ft)	6-Hr Inflow Volume / Peak Inflow
2012	2481	37.4%	373	15.0%
2011	794	22.0%	204	25.7%
2010	1429	31.3%	246	17.2%
2005	2478	49.2%	381	15.4%
2000	1486	28.1%	439	29.5%
1998	3023	14.4%	638	21.1%

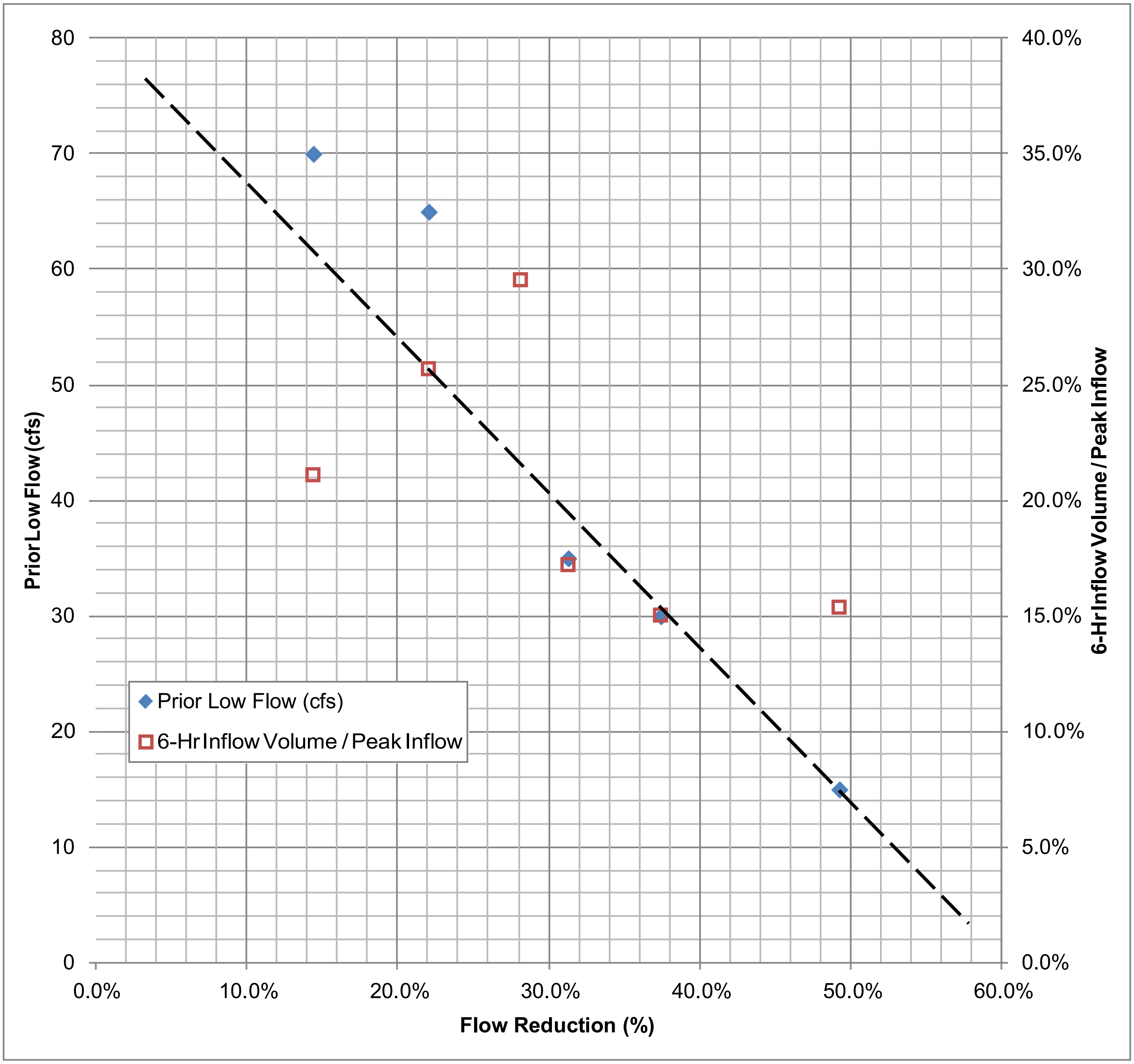

Figure 4: Effects on Flow Reduction

9. DOWNSTREAM EFFECTS

A historical case study was done on the December 2012 event to determine the impacts of Searsville Lake to the downstream reaches of San Francisquito Creek where creek capacity and flooding is an issue. The 2012 event was chosen due to the availability of stream gage data upstream of the Lake to properly estimate the amount of inflow. It is also noted that this event does have one of the highest percentages of flow reduction, and is not representative of every storm event. Due to the high flow reduction, the benefit seen in this case study will likely be on the higher end.

To perform this analysis, the recorded flow downstream will be compared with a hypothetical situation where the lake is not present. No modeling will be performed and measured data will be used. For inflow data into Searsville Lake, the methods outlined in Section 4 was used. Furthermore, two additional stream gages will be used for the study as well. The first is on Bear Creek, and the second is on Los Trancos Creek. Both these creeks join with San Francisquito Creek before entering the valley, as seen in the map in Figure 1. With Searsville, Bear, and Los Trancos, the majority of the runoff producing watershed is accounted for, and additional flows should be negligible for the purposes of this study. To determine the travel time of the flow, analyses will be performed on the recorded data, and the same value will be used for both cases. The USGS gage by the Stanford golf course will be used as the index point to determine impacts to downstream conditions.

For the observed 2012 data, the USGS gage records two peaks, as seen in Figure 5. The first can be attributed to the first Bear Creek peak (4,264cfs), along with smaller flows from Los Trancos and Searsville. Both Bear and Los Trancos peaks occur on the 23rd, at just after 3pm in the afternoon within 15 minutes of each other. This shows that travel times for both Bear and Los Trancos are similar, reaching the USGS gage at 4:30pm, giving a travel time of about 1 hour.

The second and larger peak at the USGS gage occurs at 6:45pm with a flow rate of 5,400cfs. This is attributed, for the most part, to the Searsville Lake spill (1,553cfs) combining with the second Bear Creek peak (3,275cfs). These peaks occur within half an hour, starting at 6pm. The travel time for the Bear and Searsville combined flows is about 45 minutes, slightly faster than the previous travel time. The sum hydrograph of all three of the tributaries is shown in dashed black in Figure 5.

For the hypothetical, no lake scenario, the inflow stream gage data was summed and used as the outflow for Searsville Lake. Travel distance from these stream gages toward the location of the dam was averaged to about 1 mile, which would translate into about a 15 minute travel time at a reasonable velocity of about 6 ft/s, assuming a natural channel in lieu of the lake. Therefore, the summed inflow data was lagged 15 minutes to account for travel time to the dam site. The sum of the three tributaries was then lagged 1 hour to account for the travel time to the USGS gage, which will be considered the hypothetical USGS observed data. Results can be seen in Figure 6.

The estimated peak flow for the no lake scenario is 7,351cfs, which is almost 2,000cfs higher than the observed peak flow value of 5,400cfs. This reduction is a result of a combination of both flow and time attenuation effects from the lake. The largest storm of record on San Francisquito Creek recorded a peak flow of 7,200cfs at the USGS station, which caused significant flooding in the downstream communities in 1998.

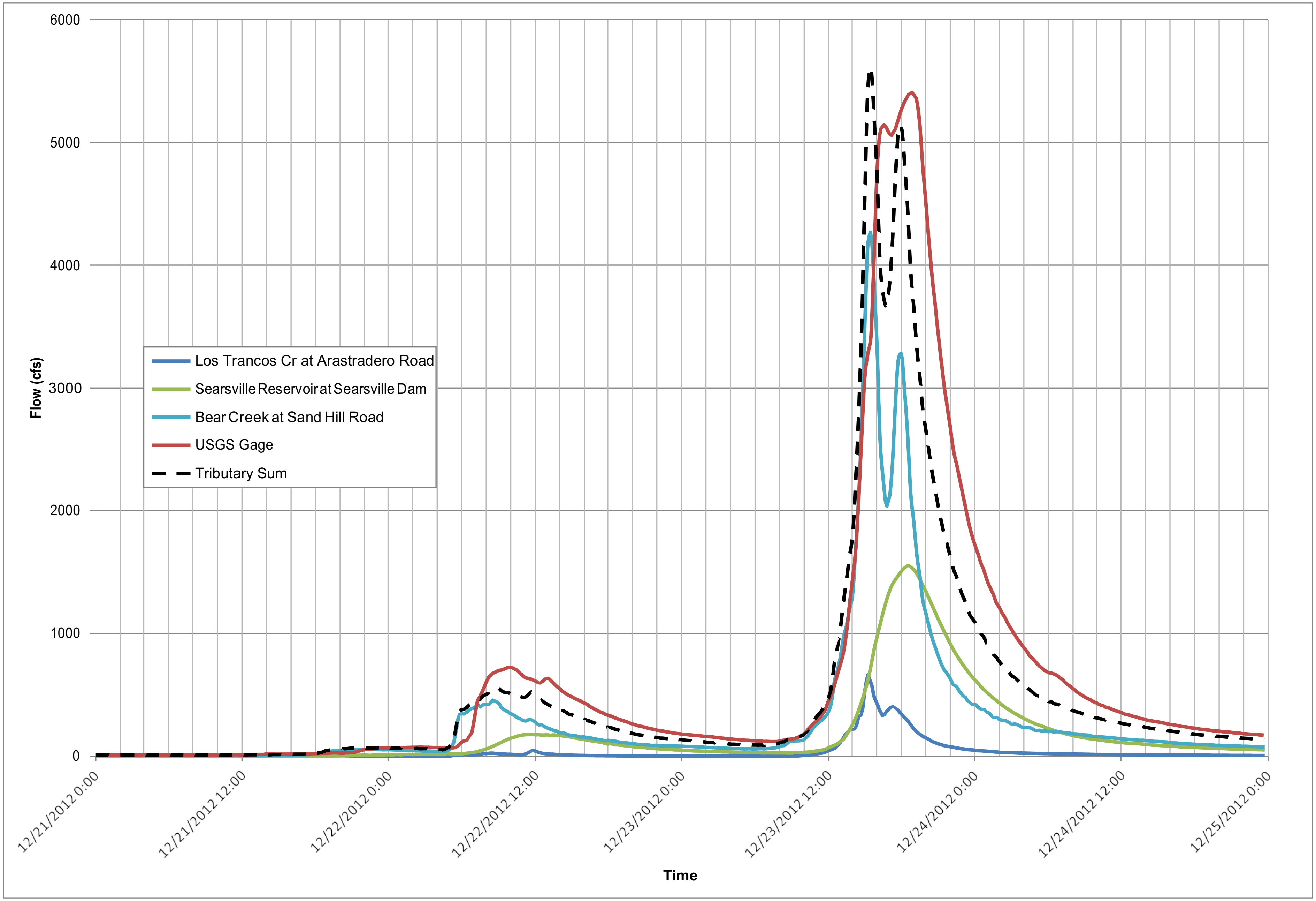

Figure 5: 2012 Observed Stream Flow

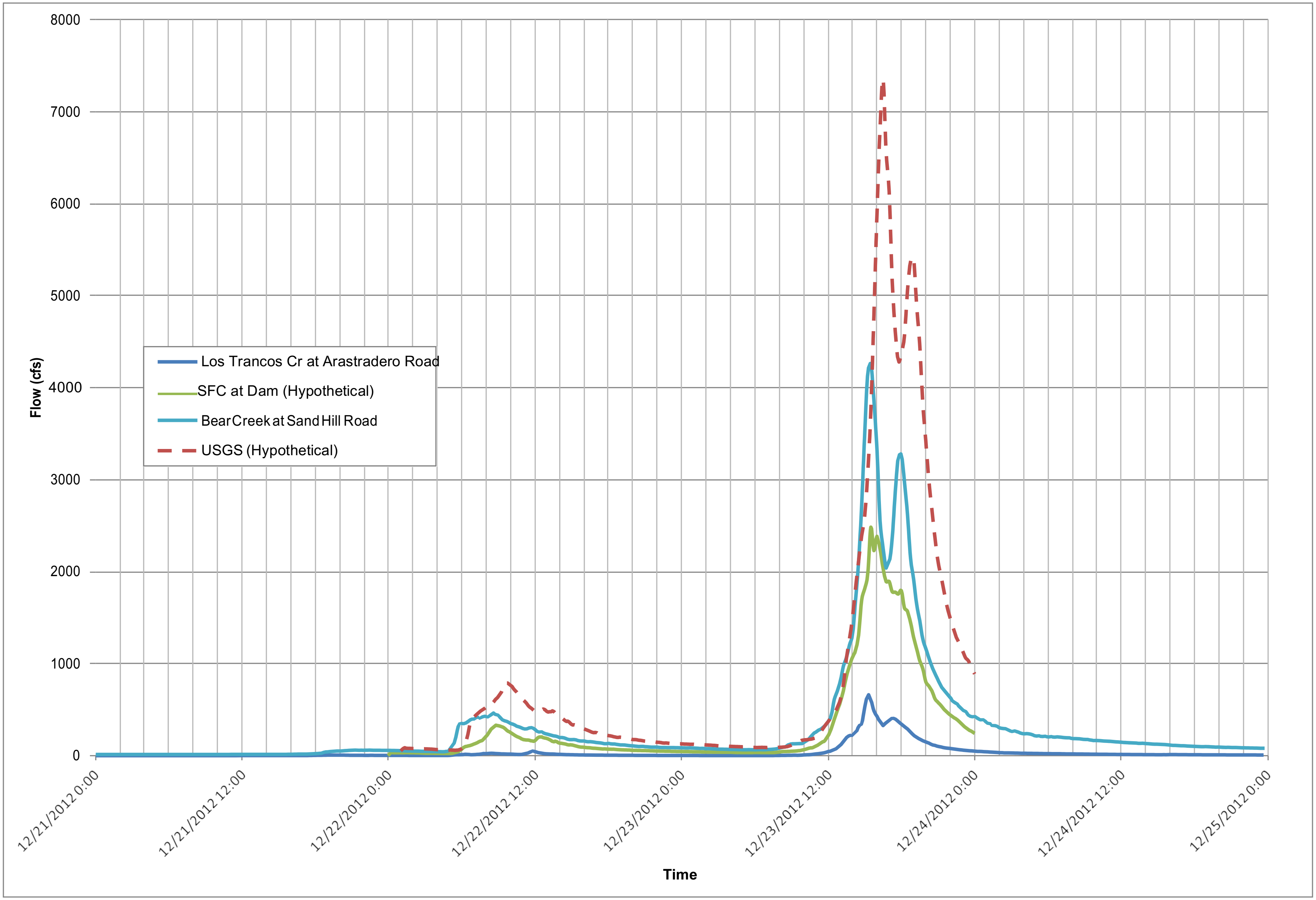

Figure 6: 2012 Hypothetical No Dam Flows

10. CONCLUSIONS

In all six events, three different parameters for each event were then analyzed to quantify the specific characteristics causing the attenuation, including antecedent rainfall, baseflow, and hydrograph shape. General conclusions from the parameters are listed below.

- When the majority (more than 80%-90%) of antecedent rainfall 24-hours before the peak intensity falls within 6 hours of the peak, there is more attenuation.
- When the baseflow prior to the peak inflow is low (less than 30cfs-40cfs), there is more attenuation.
- When the inflow volume / peak inflow is low (less than 18%-20%), meaning a thin and sharp hydrograph, there is more attenuation.

Table 4 below documents how each event performed with respect to all the parameters, and categorizes each event based on the three parameters. Events with significant attenuation are in blue, and events with nuanced attenuation are in orange, with a yes value indicating attenuation.

Table 4: Attenuation Parameter Summary

Historical Event	Flow Reduction (%)	Peak Lag Time (hrs)	24-hr Antecedent Rainfall	Prior Low Flow (cfs)	6-Hr Inflow Volume / Peak Inflow
2012	37.4%	3.25	Y	Y	Y
2011	22.0%	3.5	Y	N	N
2010	31.3%	2	Y	Y	Y
2005	49.2%	2	n/a	Y	Y
2000	28.1%	1.5	N	n/a	N
1998	14.4%	0.5	N	N	N

The results of the analysis show that Searsville Lake has available storage. Storms with the most volume concentrated in the main inflow hydrograph have the most attenuation, while storms that are spread out offer the least attenuation. In addition, the antecedent base flow conditions give a clue to the saturation of the Lake's storage system, showing that an event that occurs during high saturation will not incur much attenuation benefit. The parameters between antecedent rainfall, base flow, and hydrograph shape are likely correlated to some extent, and are probably characteristics of a slow-moving storm system.

The event in 2011 appears to be an outlier, possibly due to the significantly lower peak flow. With a maximum peak inflow to the Lake estimated at around 800cfs, it is almost half the size of the next smallest event.

The exact nature and location of the Searsville Lake storage is not known for certain, but it is hypothesized that the area behind the Lake, identified as the artificial Searsville marsh (Figure 1), is providing the storage. Once the floodplain is utilized, this area has a considerable amount of flow obstructions, as evidenced by a Manning's roughness coefficient of 0.1 in the 2D hydraulic model, and the various culverts used to convey floodwaters under road embankments.

APPENDIX B

DISTRICT'S STATEMENT

CERTIFICATION OF AGENCY TECHNICAL REVIEW
December 2015

Targeted Review

For the:

SAN FRANCISQUITO CREEK HYDROLOGY STUDY
Hydraulics, Hydrology and Geomorphology Unit
DRAFT FINAL USACE DIVISION REVIEW

Prepared by:
Jack Xu, PE Associate Civil Engineer

Under the Direction of:
Liang Xu, Ph. D, PE Engineering Unit Manager

October 2015

San Francisco District

US Army Corps
of Engineers ®

CERTIFICATION OF AGENCY TECHNICAL REVIEW

Subject: Agency Technical Review (ATR) of the **SAN FRANCISQUITO CREEK HYDROLOGY STUDY, Hydraulics, Hydrology and Geomorphology Unit, DRAFT FINAL USACE DIVISION REVIEW, October 2015**, San Francisco District.

Significant concerns and the explanation of the resolution of agency technical review comments for the subject ATR are as follows:

- None

References.

a. ATR guidance: EC 1165-2-214, 15 December 2012, Water Resources Policies and Authorities, CIVIL WORKS REVIEW.
b. The Review Management Organization for this review was the National Flood Risk Management Planning Center of Expertise (FRM-PCX).
c. The ProjnetTM DrChecks Project and Review titles are: Project: (San Francisquito) San Francisquito Creek Flood Risk Management and Review: 2015 Hydrology ATR.
d. The ATR review report is titled: Review Management Organization: National Flood Risk Management Planning Center of Expertise, REVIEW MANAGEMENT ORGANIZATION'S AGENCY TECHNICAL REVIEW REPORT, December 2015, Targeted Review, For the: SAN FRANCISQUITO CREEK HYDROLOGY STUDY, Hydraulics, Hydrology and Geomorphology Unit, DRAFT FINAL USACE DIVISION REVIEW, Prepared by: Jack Xu, PE Associate Civil Engineer, Under the Direction of: Liang Xu, Ph. D, PE Engineering Unit Manager, October 2015, San Francisco District, and contains the ATR Completion Statement.

I certify that all comments resulting from ATR of the subject report have been closed to the satisfaction of the agency technical review team and the project delivery team.

Lyn Gillespie, P.E. Chief, Engineering and Technical Services Division CESPN-ET	Date

Review Management Organization:
National Flood Risk Management Planning Center of Expertise

REVIEW MANAGEMENT ORGANIZATION'S AGENCY TECHNICAL REVIEW REPORT
December 2015

Targeted Review

For the:

SAN FRANCISQUITO CREEK HYDROLOGY STUDY
Hydraulics, Hydrology and Geomorphology Unit
DRAFT FINAL USACE DIVISION REVIEW

Prepared by:
Jack Xu, PE Associate Civil Engineer

Under the Direction of:
Liang Xu, Ph. D, PE Engineering Unit Manager

October 2015

San Francisco District

US Army Corps
of Engineers ®

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ENCLOSURE

Enclosure 1: PROJNET^{TM} DRCHECKS REPORT OF ALL COMMENTS

Enclosure 2: COMPLETION STATEMENT OF AGENCY TECHNICAL REVIEW

Agency Technical Review Report

Subject: Targeted review of the **SAN FRANCISQUITO CREEK HYDROLOGY STUDY, Hydraulics, Hydrology and Geomorphology Unit, DRAFT FINAL USACE DIVISION REVIEW, October 2015**, San Francisco District.

1. Scope and Purpose of Review. This review report documents a targeted technical review of the subject report and was conducted pursuant to EC 1165-2-214, 15 December 2012, Water Resources Policies and Authorities, CIVIL WORKS REVIEW. The review was conducted for the San Francisco District. The point of contact for the District was Patrick Sing, Project Engineer, CESPN. The ATR team (ATRT) was lead by Marc L. Masnor, CESWF-PEC-PF (Tulsa, OK). The Review Management Organization with responsibility for managing this ATR was the National Flood Risk Management Planning Center of Expertise (FRM-PCX). The review was conducted between October and November 2015.

2. References.

a. This supplement to the review report was prepared in response to EC 1165-2-214, 15 December 2012, Water Resources Policies and Authorities, CIVIL WORKS REVIEW.
b. The review documents reside online at ProjNet^{TM} (www.projnet.org), DrChecks Project and Review titles: Project: (San Francisquito) San Francisquito Creek Flood Risk Management and Review: 2015 Hydrology ATR.

3. Project Description. San Francisquito Creek forms the boundary of the Santa Clara Valley Water District’s (SCVWD) jurisdiction to the north with San Mateo County. The watershed is approximately 45 square miles, with the majority of the watershed in the rural foothills of the San Francisco Peninsula. The Creek’s watershed impacts the cities of Palo Alto, East Palo Alto, and Menlo Park. Stanford University is also a major landowner in the region and owns several reservoirs within the watershed.

San Francisquito has three main tributaries that combine to form the creek proper once it leaves the foothills and enters the urbanized valley. Bear Creek is the northernmost tributary and is unimpaired. To the south, Searsville Lake and Dam collect runoff from Alambique, Dennis Martin, Sausal, and Corte Madera Creeks. Searsville Lake offers some attenuation, but has experienced severe sedimentation over time. On the southeastern edge of the watershed, Los Trancos Creek flows unimpaired, passing Felt Lake, a diversion pond owned by Stanford. All three of these tributaries meet before traveling downstream toward the bay through urbanized neighborhoods.

The purpose of the report was to update the 2007 San Francisquito Hydrology Report by improving the following items from the old report:

- Upgrading the numerical model from HEC-1 to HEC-HMS v4.0.
- Characterizing the routing effects of Searsville Lake and dam by using a 2D hydraulic model.
- Using revised and improved methodology for design storms, loss, and Clark's hydrograph parameters (Tc & R).
- Calibrating the numerical model to historical storms.
- Performing a flood frequency analysis (FFA) on the USGS stream gage and validating the hydrologic design model to the FFA.

A hydrologic model that reflects the existing San Francisquito Creek watershed was developed. This model will be used to determine revised 1% and 10% design flows for the entire creek.

4. Review Team. The following team members met the requirements of the District and RMO for this targeted review.

ATRT Lead – Marc Masnor P.E., Civil Engineer, CESWF-PEC-PF (Tulsa, OK) – 918-669-7349, Marc.L.Masnor@usace.army.mil. Mr. Masnor is a civil works water resources planner in the Plan Formulation Section of the Southwestern Division Office (SWD) Regional Planning and Environmental Center (RPEC), headquartered in the Fort Worth District Office (CESWF) in Fort Worth, TX. He works from the Tulsa District Office (CESWT) in Tulsa, OK, 1645 S. 101st East Ave, Tulsa, OK 74128-4609. He has 37 years of experience with the Corps of Engineers, Tulsa District, Tulsa, OK.

Marc is a SWD regional technical specialist (RTS) for plan formulation and National Environmental Policy Act evaluation of flood risk management (FRM), ecosystem restoration (ECO), and water management and reallocation studies (WMRS). As a senior plan formulation specialist and regional technical specialist, he assists in the development of unique or complex formulation and analysis techniques within the framework of Corps of Engineers guidance; Federal, state, and local laws and regulations; and stakeholder interests. He has been both study manager and project manager for many Tulsa District planning studies that involved flood risk management, ecosystem restoration, comprehensive watershed studies, water supply, reservoir storage reallocation, navigation, hydropower, and chloride control. Mr. Masnor has worked in hydrology, design, project management, and civil works planning offices within the Tulsa District and has completed a wide variety of water resources studies in Kansas, Oklahoma, and Texas. Studies included the evaluation of navigation and hydropower expansion on the McClellan-Kerr Navigation system; a system of 122 small reservoirs in the Grand-Neosho Basin; chloride control evaluations in the Arkansas and Red River Basins; multiple purpose reservoirs system formulation; storage reallocation studies, regional needs studies; watershed ecosystem restoration evaluations; and several local levee, channel, detention, and buyout plans.

He currently provides support for offices within (a) the RPEC and Districts within SWD, (b) three planning centers of expertise (PCX) review management organizations (RMO) for FRM, ECO, and WMRS, and (c) multiple division office RMOs across the Corps. He has participated in or lead roughly 100 ATRs or DQCs.

(a) He supports the RPEC and the SWD as the plan formulation RTS, as an agency technical review (ATR) team member or team lead for continuing authority projects, as a district quality control (DQC) team member, and as a project delivery team (PDT) member.

(b) He supports three PCX RMOs as the ATR Team lead. In that capacity he selects and manages ATR teams to analyze pre-authorization feasibility studies conducted by Districts related to flood risk management, water management and reallocation, ecosystem restoration, and navigation. He has been the Southwestern Division Regional Manager for the FRM PCX National Manager, Eric Thaut (SPD) since 2008 through 2013. Marc participates in a national team that develops tools in support of the PCX RMOs managing body called the PCX Guild. This small team meets at the direction of the Guild to prepare supplemental review tools such as checklists, templates, and training materials for ATR and PDT teams.

(c) He also supports the Division RMOs as the ATR lead. In that capacity he selects and manages ATR teams to analyze post-authorization implementation studies including design documentation reports (DDR) and detailed project reports (DPR), and plans and specifications (P&S), generally for FRM, ECO, and WMRS.

Hydrology and Hydraulics – David Williams, CESWT – 918-669-7091, David.J.Williams@usace.army.mil. David Williams, Hydraulic Engineer, U.S.

Army Corps of Engineers, Tulsa, OK. Dr. Williams graduated Cum Laude from the University of Tulsa in 1999 with a Bachelor of Arts degree in Geology, from the University of Oklahoma in 2001 with a Master of Environmental Science, from Oklahoma State University in 2004 with a Master of Science in Environmental Engineering, and from Oklahoma State University in 2007 with a Doctor of Philosophy in Civil Engineering. He has worked for the U.S. Army Corps of Engineers for 3 years in the Tulsa District office. He currently serves as a Hydraulic Design Engineer for Tulsa District in the areas of flood modeling, flood control structure design, and climate change. Additionally, he serves as a National Hydraulic Modeling Team Lead for the USACE Modeling, Mapping, and Consequences (MC) Production Center and as a representative on the USACE Climate Change and Water Management PDT. Dr. Williams is a member of the USACE Hydrology Committee and of the USACE Extreme Storm Workgroup. He serves on a National Dam Safety Evaluation Team and has conducted several risk-based analyses in the field of Hydrology and Hydraulics. Current work includes modeling of dam break scenarios on multiple structures nationwide as well as levee certification modeling, all based on risk analysis framework. In addition to his employment with USACE, Dr. Williams is an Adjunct Professor of Civil Engineering at Oklahoma State University and a Research Associate (Geosciences) at the University of Tulsa.

5. Charge to Reviewers. A separate charge document was not developed for this targeted review. The District briefed the reviewer. The ATRT Lead's electronic meeting notice provided the location and description of review documents, review schedule, labor codes, and labor amounts. The notice also identified the District POC and provided contact information, identified the Projnet^{TM} DrChecks project and review, and stated the requirement for four part comments.

6. Summary. The ATR was completed without issues or controversy. The ATRT finding was that the District conducted a thorough peer review. The following paragraphs summarize the status of comments.

a. Critical. None.
b. Unresolved. None.
c. Lessons Learned. None.

7. Dr. Checks Report. The Projnet^{TM} DrChecks report of all comments is attached as Enclosure 1.

8. ATR Completion. Enclosure 2 contains the completion statement of agency technical review. A completion statement for a decision document would be signed by ATRT Lead, the District point of contact, and the RMO representative. Because this was a targeted review the completion statement is only signed by the ATRT Lead and the District point of contact. The District POC should provide a copy of the review report with both signatures for records.

Marc L. Masnor

Marc L. Masnor
CESWF-PEC-PF (Tulsa, OK)

Enclosure 1

PROJNET^{TM} DRCHECKS REPORT OF ALL COMMENTS

UNCLASSIFIED\\FOR OFFICIAL USE ONLY

Comment Report: All Comments
Project: San Francisquito Creek Flood Risk Management
Review: 2015 Hydrology ATR
Displaying 4 comments for the criteria specified in this report.

Id	**Discipline**	**Section/Figure**	**Page Number**	**Line Number**
6284017	Hydrology	n/a	n/a	n/a

Comment Classification: **Unclassified\\For Official Use Only (U\\FOUO)**

REVIEW CONCERN

Design rainfall values.

BASIS FOR THE CONCERN

It is stated in the report (page 48) that NOAA Atlas 14 was not used to characterize the design storm as previous studies have yielded high flows. There certainly can be value in developing a site-specific analysis in lieu of using a more generalized study such as NOAA Atlas 14, but the discussion on page 48 describing why NOAA Atlas 14 is inappropriate is limited.

SIGNIFICANCE OF THE CONCERN

Medium

ACTION NEEDED TO RESOLVE THE CONCERN

At a minimum, a more complete explanation about why NOAA Atlas 14 was excluded would be helpful on page 48. For example, how do the design values published in NOAA Atlas 14 compare with the TDS design values? How do these compare with TP-40? What factors make NOAA Atlas 14 unsuitable at this location?

Submitted By: David Williams (918-669-7091). Submitted On: Oct 30 2015

1-0 Evaluation **Concurred**

Additional narrative included in section 5.2 RAINFALL DEPTH. In summary, the depths were larger and the percentage short duration/long duration depths were larger too, resulting in higher runoffs. Comparison between NOAA-14 and District TDS equations shown for all sub-basins on new Table 7. Comparison between NOAA-14 at a point rainfall gauge station (ca. 1966) with District statistical numbers done as well in new Table 8. TP-40 shows approximately 6" for 1%, 24-hr storm, and appears closer to the District TDS equations (attachment). However, the 2" contours are rough and difficult to exact.

Submitted By: Jack Xu (4086302913) Submitted On: Nov 05 2015 (Attachment: TP_40_1p_24hr.jpg)

1-1 Backcheck Recommendation **Close Comment**
Closed without comment.

Submitted By: David Williams (918-669-7091) Submitted On: Nov 16 2015
Current Comment Status: **Comment Closed**

6284018	Hydrology	n/a	n/a	n/a

Comment Classification: **Unclassified\\For Official Use Only (U\\FOUO)**

REVIEW CONCERN

Use of the TDS regional equation.

BASIS FOR THE CONCERN

Without having a detailed knowledge of heavy precipitation events in this basin, it is assumed that they result from onshore flow and occur in part to the local orographic effect of the coastal range. It is also assumed that excessive precipitation results from specific types of weather patterns, e.g. the "Pineapple Express" or some other prevailing flow that brings relatively warm, moist air onshore. Do the storms that were used in the statistical analysis adequately represent the full range of plausible events?

SIGNIFICANCE OF THE CONCERN

Medium

ACTION NEEDED TO RESOLVE THE CONCERN

Please comment.

Submitted By: David Williams (918-669-7091). Submitted On: Oct 30 2015

1-0 Evaluation **For Information Only**
You are correct - all the major moisture that falls in the SFC watershed, and really most of the state for that matter, are from atmospheric river type events, aka pineapple express. There are sometimes very isolated and small convective storms, but these do not occur on the west side of our region, which is where SFC is located.

Our statistical analyses (which produce our TDS equations) rely on recorded rain gauge data that the District has operated - most of which were installed from 1960 to 1980, with an average record length of 30+ years.

Since all the major rain events are atmospheric rivers, the rain gauge data should reflect that as well.

Submitted By: Jack Xu (4086302913) Submitted On: Nov 04 2015

1-1 Backcheck Recommendation **Close Comment**
Closed without comment.

Submitted By: David Williams (918-669-7091) Submitted On: Nov 16 2015
Current Comment Status: **Comment Closed**

6284019 Hydrology n/a n/a n/a

Comment Classification: **Unclassified\\For Official Use Only (U\\FOUO)**

REVIEW CONCERN

Adopted design rainfall.

BASIS FOR THE CONCERN

Although the TDS equation and coefficients were provided in the report, the adopted design rainfall values were not. Discussion on page 48 would benefit from a table of values.

SIGNIFICANCE OF THE CONCERN

Medium

ACTION NEEDED TO RESOLVE THE CONCERN

Please consider adding a table of TDS design rainfall values to the report. For the sake of comparison, NOAA Atlas 14 design rainfall values would be helpful as well.

Submitted By: David Williams (918-669-7091). Submitted On: Oct 30 2015

1-0 Evaluation **Concurred**
Included new Table 7 to compare 1% 72-hr and 24-hr TDS depths to NOAA-14 depths.

Submitted By: Jack Xu (4086302913) Submitted On: Nov 05 2015

1-1 Backcheck Recommendation **Close Comment**
Closed without comment.

Submitted By: David Williams (918-669-7091) Submitted On: Nov 16 2015
Current Comment Status: **Comment Closed**

6284021 Hydrology n/a n/a n/a

Comment Classification: **Unclassified\\For Official Use Only (U\\FOUO)**

REVIEW CONCERN

Available storage in Searsville Lake.

BASIS FOR THE CONCERN

On page 13 of the technical memorandum, it is stated that "the exact nature and location of Searsville Lake not known for certain, but is hypothesized that the area behind the lake, identified as the artificial Searsville marsh, is providing the storage." With respect to storage behind the dam, the most critical volume for the hypothetical runoff events is the volume above the normal pool elevation since the additional runoff will be routed on top of this permanent or semi-permanent pool. Since this is the case, a detailed volume-elevation curve can be developed from the DEM, and the areas providing the most storage can be readily identified.

SIGNIFICANCE OF THE CONCERN

Medium

ACTION NEEDED TO RESOLVE THE CONCERN

Consider additional analysis (using the DEM) that will improve knowledge about available flood storage volume behind Searsville Dam. Historical relationships can be developed from topographic quadrangle maps and/or the original design memorandum from the project (if available).

Submitted By: David Williams (918-669-7091). Submitted On: Oct 30 2015

1-0 Evaluation **Concurred**

Additional analysis performed using the DEM, converting it to a TIN file and using a GIS tool to calculate volume at given elevations. Two storage areas were identified, formed by roadway embankments, and one storage area that includes the lake and the marsh upstream.

Since the technical memo is separate from the hydrology study and is already finalized, the data was not added to the technical memo. The design storm and calibration took into account the storage in the 2D model.

Submitted By: Jack Xu (4086302913) Submitted On: Nov 17 2015

1-1 Backcheck Recommendation **Close Comment**

Closed without comment.

Submitted By: David Williams (918-669-7091) Submitted On: Nov 20 2015

Current Comment Status: **Comment Closed**

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Patent 11/892,984 ProjNet property of ERDC since 2004.

Enclosure 2

COMPLETION STATEMENT OF AGENCY TECHNICAL REVIEW

COMPLETION OF AGENCY TECHNICAL REVIEW

A targeted agency technical review has been completed for the SAN FRANCISQUITO CREEK HYDROLOGY STUDY, Hydraulics, Hydrology and Geomorphology Unit, DRAFT FINAL USACE DIVISION REVIEW, October 2015, San Francisco District. The review was conducted as defined in the project's Review Plan to comply with the requirements of EC 1165-2-214, 15 December 2012, Water Resources Policies and Authorities, CIVIL WORKS REVIEW. During the review, compliance with established policy principles and procedures, utilizing justified and valid assumptions, was verified. This included review of: assumptions, methods, procedures, and material used in analyses, alternatives evaluated, the appropriateness of data used and level obtained, and reasonableness of the results, including whether the product meets the customer's needs consistent with law and existing US Army Corps of Engineers policy. The DQC process was found to be thorough. All comments resulting from the ATR have been resolved and the comments have been closed in DrChecks.

Marc L. Masnor, P.E.
ATR Team Leader
CESWF-PEC-PF (Tulsa, OK)

Date

Patrick Sing
Project Engineer
CESPN-ET-EW

Date

Targeted reviews are coordinated with the RMO but do not require signature by the RMO representative. A courtesy copy of the review report and signed completion statement should be provided to the RMO.

DISTRICT QUALITY CONTROL CERTIFICATION COMPLETION OF QUALITY CONTROL ACTIVITIES

The District Quality Control (DQC) of the 2015 hydrology study of the San Francisquito Creek watershed has been completed. A hydrologic model of the entire watershed, hydraulic model characterizing the routing effects of Searsville Dam, main report titled “San Francisquito Creek Hydrology Study, Draft Final, USACE Division Review”, and supporting reference documents were reviewed. Certification is hereby given that all quality control activities appropriate to the level of risk and complexity inherent in the product have been completed.

GENERAL FINDINGS

Compliance with clearly established policy principles and procedures, utilizing clearly justified and valid assumptions, has been verified. This includes assumptions; methods, procedures and materials used in analyses; alternatives evaluated; the appropriateness of data used and level of data obtained; and the reasonableness of the results. The undersigned recommends certification of the quality control process for this product.

CERTIFICATION

Certification is hereby given that all quality control activities appropriate to the level of risk and complexity inherent with the completed product.

____________________________ 09 October 2015

Janice M. Lera-Chan, P.E.
Chief, Water Resources Section
CESPN-ET-EW

Date

____________________________ ________________

Harrison S. Sutcliffe, P.E.
Chief, Engineering Branch
CESPN-ET-E

Date

District Quality Control (DQC) Review of the 2015 San Francisquito Hydrologic Study (SCVWD RESPONSE)

Background:

The Water Resources Section of the San Francisco District (SPN) conducted a DQC review of the 2015 hydrologic study of the San Francisquito Creek watershed in September 2015. The 2015 hydrologic study was compiled by the Santa Clara Valley Water District (SCVWD) and includes a HEC-HMS model, a HEC-RAS model, main report, and supporting documentation. SCVWD requests that this hydrologic study be adopted for use in the ongoing San Francisquito Creek General Investigations Feasibility Study. The feasibility study is being conducted by SPN with the San Francisquito Creek Joint Powers Authority (JPA) as the non-federal sponsor. SCVWD is a member of the JPA. A complete list of products included in the 2015 study is presented below.

Products Included in the 2015 Hydrologic Study for DQC Review:

- Main report titled “San Francisquito Creek Hydrology Study, Draft Final USACE DQC Review, September 2015”
- HEC-HMS model “Cal_SFO_2014.hms”
- HEC-RAS model “SearsvilleRAS5.prj”
- Fifteen reference documents for the main report

Prior Coordination Between SCVWD and Water Resources Section:

The Water Resources Section was given the opportunity to review and provide comments on the pre-final draft report in June 2015. At the time of this review, SCVWD had not yet requested a certification of their hydrologic study, so Water Resources Section’s review and comments did not constitute an official DQC review. The Water Resources Section initially had comments about SCVWD’s assumptions regarding the existing and future operations of Searsville Dam, and had concerns that these operations were not being accounted for in their HEC-HMS model. SCVWD attempted to address these concerns by creating Section 8 (“Future Conditions”) in the pre-final draft final report, updating their HEC-HMS model to include a scenario where the lake behind the dam would be full of sediment as a future condition, and by giving a short PowerPoint presentation to Water Resources Section staff regarding the updates to both the pre-final draft report and HEC-HMS model. The Water Resources Section thanks SCVWD for the opportunity to be part of the review process of the 2015 hydrologic study before the official DQC review commenced.

DQC Comments:

Comment #1 (Submitted by: Patrick Sing)

- SCVWD communicated to Water Resources Section that one of the main reasons for conducting this 2015 hydrologic study was to account for attenuation of peak flows caused by the dam at Searsville Lake and that this attenuation was not addressed in SCVWD’s 2007 hydrologic study of the San Francisquito Creek watershed. However, the main report does not include much background information of the dam itself. Background information could include (but not necessarily be limited to): original purpose of the dam, construction date of the dam, current capacity of the dam, and sedimentation rates behind the dam. The only background information provided about the dam is in Section 2.5 (page 6) of the main report regarding the square mileage of the watershed that is behind the dam. Because the attenuation of flows caused by the dam was a driving force for conducting the 2015 hydrologic study, it is recommended that additional background information of the dam be included either in Section 2.5 or Section 8.2 of the main report.

SCVWD Response to Comment #1:

- Concur. Requested background information for Searsville Dam is added to the narrative in section 2.5.

Comment #2 (Submitted by: Janice Lera-Chan)

- SCVWD compiled a technical memorandum, dated March 25, 2015, on the effect of Searsville Lake on large storm events. It is mentioned on page 8 of the main report. It is recommended that the memo either be incorporated in the main report or it be included as attachment, rather than just made as a reference. It is also recommended that a plate (i.e. figure map) be added to the main report that focuses on the Searsville Lake area that shows the roads crossings, culvert restrictions and what is referred to as wetlands/small water bodies.

SCVWD Response to Comment #2:

- Concur. The technical memorandum is added as Appendix A, in addition to being a reference. An additional figure/map was added (now Figure 2) detailing the intricacies of the upstream Searsville Lake area, including the wetlands and culvert crossings. It's worth noting that it was very difficult in finding any sort of map that showed the trails and private roads crossing the Jasper Ridge Preserve in Stanford. However, the figure should have all the pertinent information necessary to understand the operation of the upland area.

Comment #3 (Submitted by: Patrick Sing)

- Section 8.2.2 of the main report refers to a "Stanford steering committee". This is in reference to the steering committee commissioned by Stanford University to address the future of the dam at Searsville Lake. To avoid confusion with other steering committees present at Stanford University, the Water Resources Section recommends referring to this committee as the "Searsville Alternatives Study Committee". This is the same title that is used in the recommendation report that was produced by the committee in April 2015 (and is included as a reference to the main report).

SCVWD Response to Comment #3:

- Concur. Steering committee revised to Searsville Alternatives Study Committee (SASC)

Comment #4 (Submitted by: Patrick Sing)

- The Water Resources Section recommends that Section 8.2.2 of the main report be expanded to include further background information on the Searsville Alternatives Study Committee. Background information could include (but not be limited to): reason for why the committee was founded, who participates on the committee, and responsibilities of the committee.

SCVWD Response to Comment #4:

- Concur. Relevant information added to section 8.2.2, with a more clear reference to the Stanford Alternatives Study report.

Comment #5 (Submitted by: Janice Lera-Chan)

- Section 8.2.2 of the main report briefly states that a comparison was made between a scenario where Searsville Lake is filled in with sediment and a scenario where an orifice at the dam base was created and the sediment inside the lake was excavate. How much sediment would be excavated? Recommend a table showing the existing and future discharges and timing for Searsville these scenarios.

SCVWD Response to Comment #5:

- Additional language clarified the sediment filled scenario and the orifice scenario. However, the orifice details are unknown. The steering report does not specify the size, shape, or invert elevation of the "opening". Therefore, we are unable to perform any calculations. Discussion was added explaining this as well in 8.2.2.

Comment #6 (Submitted by: Patrick Sing)

- Section 2.2 of the main report notes that the Curve Number method and Clark's Unit Hydrograph was selected as the loss method and transform method in part because of its successful application to other watersheds within the boundaries of SCVWD. If possible, please provide the names of a couple of these watersheds for comparison of their sizes and shapes to the San Francisquito Creek watershed.

SCVWD Response to Comment #6:

- Added reference to the Lower Peninsula Study (2007) that was also Corps ATR'd, as well as a San Tomas/Saratoga Creek study (2013) that also used Clark's and CN method. Relative basin areas were added too. Basin sizes are within the range of San Francisquito (20-45 sq mi for the other studies). We feel Lower Peninsula Study would be a good comparison watershed since it is adjacent to San Francisquito. However, given the extensive historical calibration performed, any method would have probably been appropriate.

Comment #7 (Submitted by: Patrick Sing)

- Please provide a short explanation in Section 2.4 of the main report about why the Muskingum-Cunge method was selected as the routing method in the HEC-HMS model. Phone communication between SCVWD and Water Resources Section indicates that Muskingum-Cunge was selected because of its application to other SCVWD projects of similar nature to the San Francisquito Creek watershed - if so, the main report should include this information and further elaborate.

SCVWD Response to Comment #7:

- Muskingum-Cunge further explained. Table 19 in HEC-HMS technical reference manual shows it to be the most robust in performing routing. Other District studies that use Muskingum-Cunge are the same as the reports in Comment #6.

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